

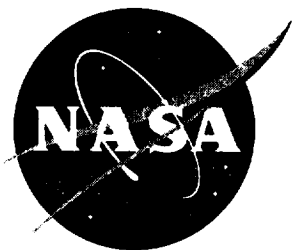
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# Mars Global Reference Atmospheric Model (Mars-GRAM 3.34): Programmer's Guide

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*C.G. Justus, B.F. James, and D.L. Johnson*





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## **ACKNOWLEDGMENTS**

We wish to thank Pete Theisinger and Pat Esposito, NASA Jet Propulsion Lab, who suggested the need for this Mars-GRAM programmer's guide and were instrumental in securing support for this activity from NASA Headquarters, Planetary Exploration Office, Mars Orbiter Program, project 215-000-42. Work was performed by the NASA Marshall Space Flight Center, Electromagnetics and Aerospace Environments Branch, EL23. We are grateful to Belinda Hardin for her expert assistance in preparing this report and to Margaret Alexander for her skillful editing of the draft.

## **PREFACE**

The effort required for the preparation of this report was sponsored by the Mars Global Surveyor Project, through NASA Jet Propulsion Laboratory (Sam Dallas JPL Mission Manager), under project 215-000-042. Technical questions on the Mars-GRAM may be addressed to Dr. C. G. Justus, EL23/CSC, NASA Marshall Space Flight Center, Huntsville, Alabama 35812 (205-544-3260; e-mail [jere@profiles.msfc.nasa.gov](mailto:jere@profiles.msfc.nasa.gov)).

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## TECHNICAL MEMORANDUM

### **Mars Global Reference Atmospheric Model (Mars-GRAM Version 3.34): Programmer's Guide**

## **1. INTRODUCTION**

### **1.1 Background**

The Mars Global Reference Atmospheric Model (Mars-GRAM) was developed (Johnson et al., 1989; Justus 1990, 1991; Appendix B, version 2.21) as an engineering-oriented, empirical model of the Mars atmosphere. The model is based on surface and atmospheric temperature data observed during the Mariner and Viking (orbiter and lander) missions and on surface pressure data observed by Viking landers. At higher altitudes (above about 120 km), Mars-GRAM is based on the Stewart (1987) thermospheric model given in Pitts et al., (1990?). The model provides both mean and mountain-wave perturbed atmospheric density for any location (height, latitude, longitude) and time (seasonal, diurnal). Other atmospheric variables include atmospheric temperature, pressure, and wind components. Dust storm effects, controlled by user-selected options, are provided for the atmospheric parameters.

A second official release of Mars-GRAM (James and Justus, 1993; Appendix C, version 3.1) added several new capabilities, e.g., the option to simulate either local-scale or global-scale dust storms and density perturbations from tidal waves by the Zurek wave model given in Pitts et al. (1990?).

Table 1-1 gives a brief history of Mars-GRAM program development through the current version — 3.34. Newest features include (1) a limitation based on atmospheric stability considerations for magnitude of mountain-wave density perturbations, (2) comparisons of density, temperature, and pressure with the COSPAR reference atmosphere (Pitts et al., 1990?), and (3) a new method for estimating the diurnal range of surface temperature based on diurnal variability of surface-absorbed solar energy. Technical descriptions of these new features are discussed in Section 3.0.

**Table 1-1. History of Mars-GRAM Program Versions (Page 1 of 2)**

Version	Date	Comments
1.00	5/20/88	Preliminary version with earlier Stewart thermosphere model and no realistic latitude-longitude variation. Documented in ED44-5-20-88 preliminary report.
2.00	7/1/89	Version documented in July, 1989 technical report. Has newer Stewart thermosphere model and realistic latitude-longitude variability.
2.10	9/2/89	Adds version numbers to main and all subroutines. Corrects formats 790 and 795 in DATASTEP subroutine.
2.11	10/2/89	Corrects "ATIO" to "RATIO" and "FH" to "PFH" in THERMOS subroutine. Corrects MARSGRAM, ATMOS2, DATASTEP, PRESSURE, PSURFACE, STEWART2, STRATOS, TEMPS, and TSURFACE to have lines <= 72 characters in length.
2.20	10/7/89	Corrects illegal log call in THERMOS by adding ES factors to ZF in ATMOS2. Adds EScalc subroutine in STEWART2. Changes name of terrain height file to HEIGHTS.DAT
2.21	10/8/89	Removes character data from COMMON DATA and puts it in new COMMON FILENAME.
2.22	11/16/89	Adds REAL J2 to RELIPS, and REAL nmals to PSURFACE. Changes Julian date by -0.5 to be consistent with astronomical convention of day starting at Greenwich noon. ORBIT adds back 0.5 to Julian day for consistency with derivation of coefficients.
3.0	10/14/91	Adds option for local-scale dust storm, and Zurek wave perturbation model. Allows heights to go "below" local terrain height and return "realistic" pressure, density and temperature, not the surface values. Both Interactive and Batch versions available. Batch version uses NAMELIST input, and is completely modular, so main driver program can easily be replaced by any calling program, such as a trajectory simulation program.
3.1	12/17/92	Change comments and code for DENSRP output to perturbations in %; change DENSLO output file to DENSRM, containing random perturbation magnitude in %; change DENSHI output file to DENSWA, containing wave perturbation in %; add DENSWA to the OUTPUT file. Modify DENSHI and DENSLO to include the wave perturbation amplitude. Delete several unused variables from declaration statements in MAIN routine and subroutines SETUP, ATMOS2, PSURFACE, STEWART2, DZDUST, THERMOS, and STRATOS.
3.1	3/14/94	Transferred version 3.1 to MSFC Unix environment and tested.
3.2	11/28/94	Corrected DENSHI, DENSLO initial value problem. Added parameter value output to DATASTEP. Modified DZDUST to use same dust storm start time and intensity as lower altitude. Changed output file units to iu0 for messages (normally screen) and iup for LIST output (iup = 0 also suppresses LIST and other output in batch version).

**Table 1-1. History of Mars-GRAM Program Versions (Page 2 of 2)**

Version	Date	Comments
		Corrected error in calculation of time-step correlations. Added line number codes in columns 73-80. Sorted MARSSUBS into alphabetical order by line number codes. Renamed Commons RAND to RANDCOM and DATA to DATACOM. Modified E-format in LIST output to have a leading digit. Made code consistent for indentation of If..Then..Else segments and Do..Continue loops. Moved NAMELIST read into SETUP for batch version and removed commons from the batch main (to simplify use of SETUP and DATASTEP as subroutines in other driver programs). Deleted additional unused variables in ATMOS2 and ORBIT. Defined pi180 in DATASTEP and corrected NVAR to NVARX. Corrected slight inconsistency in pressure interpolation in subroutine STRATOS. Added time (rel. to initial time) in sols to standard LIST file. Added time and solar longitude to OUTPUT list.
3.3	2/7/95	Simplified vertical interpolation method in subroutine STRATOS. Added DENSLO and DENSXI output files back ("1 sigma" density envelopes). Corrected erroneous comments associated with file open statements in batch version code. Added maxfiles option to suppress output of TMAX, TMIN and TAVG files for systems that cannot have more than 16 files open at one time (i.e. set maxfiles = 16 in Block Data routine).
3.31	3/28/95	Added check for density perturbations not to exceed value set by wave instability (i.e. maximum perturbation magnitude consistent with $d\text{-theta}/dz > 0$ ). Ensured wave amplitudes are zero if wave perturbation model is not selected. Added output of F10.7 at 1AU and Mars orbit.
3.32	4/11/95	Added COSPAR NH mean atmosphere and output of density deviations from COSPAR values (also new option logscale =2). Suppress output of NSWIND and EWWIND if maxfiles = 16.
3.33	8/9/95	Takes polar cap radius from Alb function and makes it a separate function, polecap. Uses new regressions for Tavgb versus Absorb (the daily average surface-absorbed solar flux). Uses new regression for diurnal temperature amplitude (Tamp) versus Qa [the diurnal range (midnight-noon difference) in surface-absorbed solar flux]. These changes in temperature regressions are all in the Tsurface subroutine.
3.34	11/1/95	Added comments for JPL Programmer's Guide. Corrected logic error in density to OUTPUT file (added format 810). Corrected problem with crlat and polar in Tsurface. Corrected semi-diurnal term in dusty-case wave model. Corrected term in maximum mountain-wave perturbation model.



## 2. OVERVIEW OF THE MARS-GRAM PROGRAM

The Mars-GRAM program consists of four FORTRAN source code files:

- (1) The Interactive form main program is MARSGRAM.FOR (or marsgram.f on UNIX machines)
- (2) The Batch (subroutine) form is MARSGRMB.FOR (or marsgrmb.f)
- (3) The Setup subroutine, used only in the batch form, is SETUP.FOR (or setup.f)
- (4) All other subroutines are MARSSUBS.FOR (or marssubs.f).

Throughout this report, names of programs, subroutines, and variables appear either as all-capitals or as upper/lower case names. The FORTRAN compiler option used is assumed to be case-insensitive.

Since version 3.2, all program code now has line numbers in columns 73-80. Line numbers consist of a four-character code (MARS for the interactive main, MARB for the batch main, SETU for the setup subroutine, etc.) and a three-digit number. For code inserted since version 3.2, an additional single letter appears in column 80.

Table 2-1 gives a simplified "map" of the Mars-GRAM programs by indicating names of subroutines and functions, 4-character code used on source file line numbers, and calling subroutine(s). Appendix A gives complete descriptions of the interactive and batch main programs, setup subroutine, and other subroutines. Except for the setup subroutine, all functions and subroutines are listed in Appendix A in alphabetic order by 4-character code.

Many program variables are passed between routines via "common" blocks. Table 2-2 lists the seven common blocks and subroutines that use them. Descriptions in Appendix A include definitions of all input, output and local variables, except those pass through these common blocks. Table 2-3 lists variables in the common blocks, including common block name, variable name, variable type, and description of the variable.

The interactive form of the program prompts the user for all input (with exception of data files HEIGHTS.DAT and COSPAR.DAT). The batch form reads and loads all data by the setup subroutine. The combination of setup routine and subroutines in marssubs.f are particularly suitable for adaptation as subroutines in user programs (e.g., orbital propagator and trajectory dynamics programs). See discussion of the batch form (MARB) in Appendix A and in Section 4.

Both the interactive and batch forms are essentially drivers for the DATASTEP (and in turn the ATMOS2) subroutine (details in Appendix A). A brief outline of the process steps in Mars-GRAM subroutines follows:

#### DATASTEP

1. Evaluate terrain height via TERRAIN subroutine
2. Obtain orbital and solar positions via ORBIT subroutine
3. Compute dust storm factors via DUSTFACT subroutine
4. Obtain pressure gradients for winds: call ATMOS2 at the current location  $\pm 2.5^\circ$  latitude and longitude

#### ATMOS2

5. Calculate surface temperature via TSURFACE subroutine
6. Compute lapse rates of atmospheric temperature via GAMMA subroutine
7. Evaluate temperatures at "significant levels" (0, 5, 15, 30, 50 and 75 km) via TEMPS subroutine
8. Obtain surface pressure via PSURFACE routine
9. Calculate atmospheric pressure at significant levels via PRESSURE routine  
i.e., if desired height is:
10. Below 75 km, interpolate between significant levels
11. Above the base of the thermosphere, use STEWART2
12. Between 75 km and the base of the thermosphere, interpolate via STRATOS subroutine

#### DATASTEP

13. Use pressure gradients, density, and Coriolis parameter to obtain wind components by the areostrophic (thermal wind) relations
14. Apply viscous damping correction to areostrophic wind components



15. Compute random (mountain wave) perturbations in density (maintain proper correlation with previous perturbation value)
16. Verify that random perturbation does not exceed stability limit
17. Compute Zurek (tidal) wave model density perturbation
18. Add perturbations to mean value of selected perturbation model.

**Table 2-1. Map of Mars-GRAM Programs and Names of Subroutines, Functions, 4-character Code, and Calling Subroutines**

Subroutine Name	Code	Called By
-----	----	-----
ATMOS2	ATM2	Datastep
Block Data	BLKD	N/A
cospar	COSP	Datastep
Dustfact	DSTF	Datastep
Datastep	DSTP	MarsGRAM(Main), Marsgrmb(Main)
DZDUST	DZDS	ATMOS2, STEWART2
ESCAL	ESCL	ATMOS2, STEWART2
gamma	GAMA	ATMOS2
orbit	ORBT	MarsGRAM(Main), Datastep, SETUP
Pressure	PRES	ATMOS2
PRSEAS	PRSE	ATMOS2, Psurface, STEWART2
Psurface	PSRF	ATMOS2
RELLIPS	RLPS	MarsGRAM(Main), ATMOS2, Datastep, Psurface, STEWART2, THERMOS, SETUP
SETUP	SETU	Marsgrmb(Main)
Stratos	STRA	ATMOS2
STEWART2	STW2	ATMOS2
THERMOS	THRM	STEWART2
Temps	TMPS	ATMOS2
Tsurface	TSRF	ATMOS2
Wavepert	WAVE	Datastep
Function Name	Code	Called By
-----	----	-----
Alb	ALBL	Tsurface
ampint	AMPN	Wavepert
Cp	CPOT	ATMOS2
phasint	PHSN	Wavepert
polecap	POLC	Alb, Tsurface
PPND	PPND	Datastep
Random	RAND	MarsGRAM(Main), Datastep, SETUP
Tdiurnal	TDIR	Tsurface
Terrain	TERN	MarsGRAM(Main), Datastep, SETUP

**Table 2-2. Common Blocks and Subroutines**

Common	Used By
cosparnh	MarsGRAM, cospar, Datastep, SETUP
DATAOM	MarsGRAM, Block Data, Dustfact, Datastep, SETUP
FILENAME	MarsGRAM, Datastep, SETUP
RANDCOM	MarsGRAM, Random, SETUP
TERHGT	MarsGRAM, Terrain, SETUP
THERM	MarsGRAM, ATMOS2, STEWART2, SETUP
WAVEDAT	MarsGRAM, Block Data, Wavepert

**Table 2-3. Variables in the Common Blocks (Page 1 of 2)**

<u>COSPARNH</u>		
zc(159)	REAL*4	COSPAR heights (km)
tc(159)	REAL*4	COSPAR temperatures (K)
pc(159)	REAL*4	COSPAR pressures
dc(159)	REAL*4	COSPAR densities
 <u>DATACOM</u>		
DTR	REAL*4	factor for degrees to radians
BETA	REAL*4	parameter for computing viscosity of CO2
SVAL	REAL*4	parameter for computing viscosity of CO2
DAY	REAL*4	length of sidereal day (hours)
CORFAC	REAL*4	Coriolis factor for computing winds
NPOS	INTEGER*4	maximum number of positions
NVARX	INTEGER*4	x-code for plotable output (see Table 2-3)
NVARY	INTEGER*4	y-code for plotable output (see Table 2-3)
logscale	INTEGER*4	units for pressure and density output (0 = MKS, 1= log-base-10, 2=% deviation from COSPAR)
dustlat	REAL*4	latitude of local scale dust storm
dustlon	REAL*4	longitude of local scale dust storm
dusthgt	REAL*4	height of local scale dust storm
radmax	REAL*4	maximum radius of local scale dust storm
Rref	REAL*4	Mars radius (km) of Cain 6.1 mb reference ellipse
modpert	INTEGER*4	perturbation model number
als0	REAL*4	initial areocentric longitude of sun
intens	REAL*4	dust storm intensity value
iu0	INTEGER*4	unit number for screen output
iup	INTEGER*4	unit number for LIST output (set=0 for no LIST)
maxfiles	INTEGER*4	maximum number of files that compiler can open
 <u>FILENAME</u>		
lstfl	CHAR*12	name of LIST file
outfl	CHAR*12	name of OUTPUT file
 <u>RANDCOM</u>		
IX	INTEGER*4	intermediate variable for random numbers
IY	INTEGER*4	intermediate variable for random numbers
IZ	INTEGER*4	intermediate variable for random numbers
 <u>TERHGT</u>		
th(19,19)	REAL*4	terrain height versus latitude and longitude
 <u>THERM</u>		
F107	REAL*4	10.7 cm solar flux at Earth position (1AU)
stdl	REAL*4	number of std. dev. for thermospheric variation

**Table 2.3. Variables in the Common Blocks (Page 2 of 2)**

<u>WAVEDAT</u>		
ampc100(12)	REAL*4	diurnal wave amplitude vs height, clear, lat=00
phc100(12)	REAL*4	diurnal wave phase vs height, clear, lat=00
ampd100(12)	REAL*4	diurnal wave amplitude vs height, dusty, lat=00
phd100(12)	REAL*4	diurnal wave phase vs height, dusty, lat=00
ampd200(12)	REAL*4	semidiurnal wave amplitude vs height, clear, lat=00
phd200(12)	REAL*4	semidiurnal wave phase vs height, clear, lat=00
ampc120(12)	REAL*4	diurnal wave amplitude vs height, clear, lat=20
phc120(12)	REAL*4	diurnal wave phase vs height, clear, lat=20
ampd120(12)	REAL*4	diurnal wave amplitude vs height, dusty, lat=20
phd120(12)	REAL*4	diurnal wave phase vs height, dusty, lat=20
ampd220(12)	REAL*4	semidiurnal wave amplitude vs height, clear, lat=20
phd220(12)	REAL*4	semidiurnal wave phase vs height, clear, lat=20
ampc145(12)	REAL*4	diurnal wave amplitude vs height, clear, lat=45
phc145(12)	REAL*4	diurnal wave phase vs height, clear, lat=45
ampd145(12)	REAL*4	diurnal wave amplitude vs height, dusty, lat=45
phd145(12)	REAL*4	diurnal wave phase vs height, dusty, lat=45
ampd245(12)	REAL*4	semidiurnal wave amplitude vs height, clear, lat=45
phd245(12)	REAL*4	semidiurnal wave phase vs height, clear, lat=45



### 3. NEW MARS-GRAM FEATURES

#### 3.1 Stability-Limited Mountain Wave Perturbations

A mountain-wave density perturbation model has been part of Mars-GRAM from the beginning. Recently noted is that effects of atmospheric stability should limit amount of growth with height attained from the mountain wave model.

Deviation of the convective stability limit on density perturbations incorporated into Mars-GRAM 3.34 is as follows:

Let the total atmospheric density be  $\rho = \rho_0 + \rho'$ , where  $\rho_0$  is the mean value and  $\rho'$  is the mountain-wave perturbed value. Static instability (density overturning) would result if the density were to increase with height. Thus stability requires that

$$d\rho/dz = d\rho_0/dz + d\rho'/dz < 0 \quad , \quad (1)$$

or

$$d\rho'/dz < -d\rho_0/dz = \rho_0/H \quad , \quad (2)$$

where  $H$  is the scale height. If we approximate  $(d\rho'/dz)$  as  $2 \rho'_{\max}/L$ , where  $L$  is the vertical scale (or wavelength), then the stability limit for density overturning is

$$\rho'_{\max}/\rho_0 < L/(2 H) \quad . \quad (3)$$

A more stringent stability condition (usually) than density overturning is the convective stability limit that temperature lapse rate  $(-dT/dz)$  not exceed adiabatic lapse rate  $(g/C_p)$ , where  $g$  = gravity,  $C_p$  = specific heat at constant pressure). Thus, the convective stability constraint means that

$$-(dT_0/dz + dT'/dz) < g/C_p \quad , \quad (4)$$

or

$$-dT'/dz < (g/C_p + dT_0/dz) \quad . \quad (5)$$

If we approximate  $-dT'/dz$  as  $2 T'_{\max} / L$ , the convective stability limitation then becomes

$$T'_{\max} / T_0 < (g/C_p + dT_0/dz) L / (2 T_0) \quad , \quad (6)$$

or, in terms of the Brunt-Vaisala frequency,  $\omega_B$ ,

$$T'_{\max} / T_0 < \omega_B^2 L / (2 g) \quad . \quad (7)$$

If first order versions of the perturbed perfect gas law and hydrostatic balance relations,

$$p' / p_0 = \rho' / \rho_0 + T' / T_0 \quad , \quad (8)$$

and

$$d(p' / p_0) / dz = (1 / H) (T' / T_0) \quad (9)$$

are used to convert the temperature perturbation in equation (7) to a density perturbation. The convective stability limit on density perturbations then becomes

$$\rho' / \rho_0 < [\omega_B^2 L / (2 g)] [1 + L / (2 H)] \quad . \quad (10)$$

This convective stability limit, via equation (10), on allowable magnitude for mountain-wave perturbations has now been incorporated into the subroutine DATASTEP (DSTP199c), with a constraint that the density overturning condition of equation (3) also be met (DSTP199d). See further discussion of the DATASTEP subroutine in Appendix A.

### 3.2 Comparison to COSPAR Reference Atmosphere

Mars-GRAM Version 3.34 includes a comparison of model values of density, temperature, and pressure with those of the COSPAR reference atmosphere (Table XI of Pitts, et al., 1990?). COSPAR data values are read in as a height array, from a file named COSPAR.DAT. COSPAR values for a desired height are found by interpolating between heights in the tabular data. See discussion of the subroutine COSPAR in Appendix A for technical details of the methodology.



### 3.3 New Surface Temperature Parameterizations

In early versions of Mars-GRAM, surface temperatures were estimated (TSURFACE subroutine) by empirically-derived regressions of temperature versus  $A$ , the daily average amount of solar radiation absorbed at the surface. Separate regressions were used for daily minimum and daily maximum temperature, via

$$T_{\min} = a_{\min} + b_{\min} A + c_{\min} A^2 \quad (11)$$

and

$$T_{\max} = a_{\max} + b_{\max} A + c_{\max} A^2 \quad , \quad (12)$$

with average daily temperature of  $(T_{\min} + T_{\max})/2$ .

A recent re-analysis of original Viking lander and InfraRed Thermal Mapper (IRTM) data, yielded an improved approach for estimating surface temperatures. First, an improved method is used to compute surface absorption,  $A$ , via

$$A = \langle \tau \rangle (1 - a) F_0 \langle \cos(\theta) \rangle \quad , \quad (13)$$

where  $\langle \tau \rangle$  is the daily average solar transmittance,  $a$  is the surface albedo (from ALB function),  $F_0$  is the top-of-atmosphere, direct-normal solar flux (for given latitude and day), and  $\langle \cos(\theta) \rangle$  is the daily average of cosine of solar zenith angle,  $\theta$ . The average transmittance is computed by methods of Justus and Paris (1985), via

$$\langle \tau \rangle = \varpi / 2 + (1 - \varpi / 2) \exp(-\delta / \mu_0) \quad , \quad (14)$$

where  $\varpi$  is the single-scatter albedo of the dust (taken to be 0.85),  $\delta$  is the optical depth of the dust (taken to be 0.3), and  $\mu_0$  is the cosine of the noontime solar zenith angle, given by

$$\mu_0 = \sin(\varphi) \sin(\varphi_s) + \cos(\varphi) \cos(\varphi_s) \quad , \quad (15)$$

where  $\varphi$  is local latitude and  $\varphi_s$  is latitude of the Sun.

The simplified relation of equation (14) was compared with the results of a subroutine (FFACT) developed by Davies (1979) from accurate Monte Carlo radiative transfer

calculations. Equation (14) results were found to agree with FFACT values within a root-mean-square value of about 0.03, or roughly the same accuracy level as FFACT values reproduce original Monte Carlo simulations (Davies, 1979).

With surface absorption,  $A$ , determined from equation (13), new regression relations were derived for  $T_{avg}$ , the daily average temperature via

$$T_{avg} = a + b A + c A^2, \quad (16)$$

if the latitude is outside the polar cap boundary, and

$$T_{avg} = a_{cap} + b_{cap} A - c_{cap} P, \quad (17)$$

if latitude is inside the polar cap boundary.  $P$  is a polar cap correction that varies from 0 at the polar cap boundary to a maximum of 1 at the pole, when the cap boundary is at its largest seasonal value (factor polar in TSURFACE, line TSRF 35, Appendix A).

New methodology for surface temperature estimates assumes that the daily range of surface temperatures,  $T_{amp} = (T_{max} - T_{min})$ , is proportional to the daily range of surface absorption,  $Q$ , where  $Q$  is given by

$$Q = \langle \tau \rangle (1 - a) F_0 [ \langle \cos(\theta) \rangle - \mu_n ] / 2, \quad (18)$$

where the symbolism is the same as for equation (13) and  $\mu_n$  is the midnight solar zenith angle, via

$$\mu_n = \sin(\varphi) \sin(\varphi_s) - \cos(\varphi) \cos(\varphi_s), \quad (19)$$

for latitudes at which the Sun is above the horizon at midnight; otherwise,  $\mu_n = 0$ .

The daily surface temperature range is determined from

$$T_{amp} = 0.16 Q \quad (20)$$

and daily minimum and maximum surface temperatures are given by

$$T_{\min} = T_{\text{avg}} - T_{\text{amp}} \quad (21)$$

$$T_{\max} = T_{\text{avg}} + T_{\text{amp}} \quad (22)$$

For additional technical description of the new surface temperature methodology, see subroutine TSURFACE in Appendix A.

The new regressions make relatively little difference in the average surface temperature. However, for cases in which the daily average absorption,  $A$ , is relatively large while the daily range in surface absorption,  $Q$ , is small, a significant change (reduction in daily temperature range) from the previous regressions can occur. This effect, illustrated in Figure 1 is most significant at high northern latitudes during northern hemisphere summer (near  $L_S = 90^\circ$ ) and at high southern latitudes during southern hemisphere summer (near  $L_S = 270^\circ$ ). Changes in these seasons and latitude ranges would be apparent in revised plots of surface temperature analogous to Figures 1, 2, and 3 of Appendix B. The reduced diurnal range in temperatures that results from the new regressions is considered to be significantly more realistic in these cases.

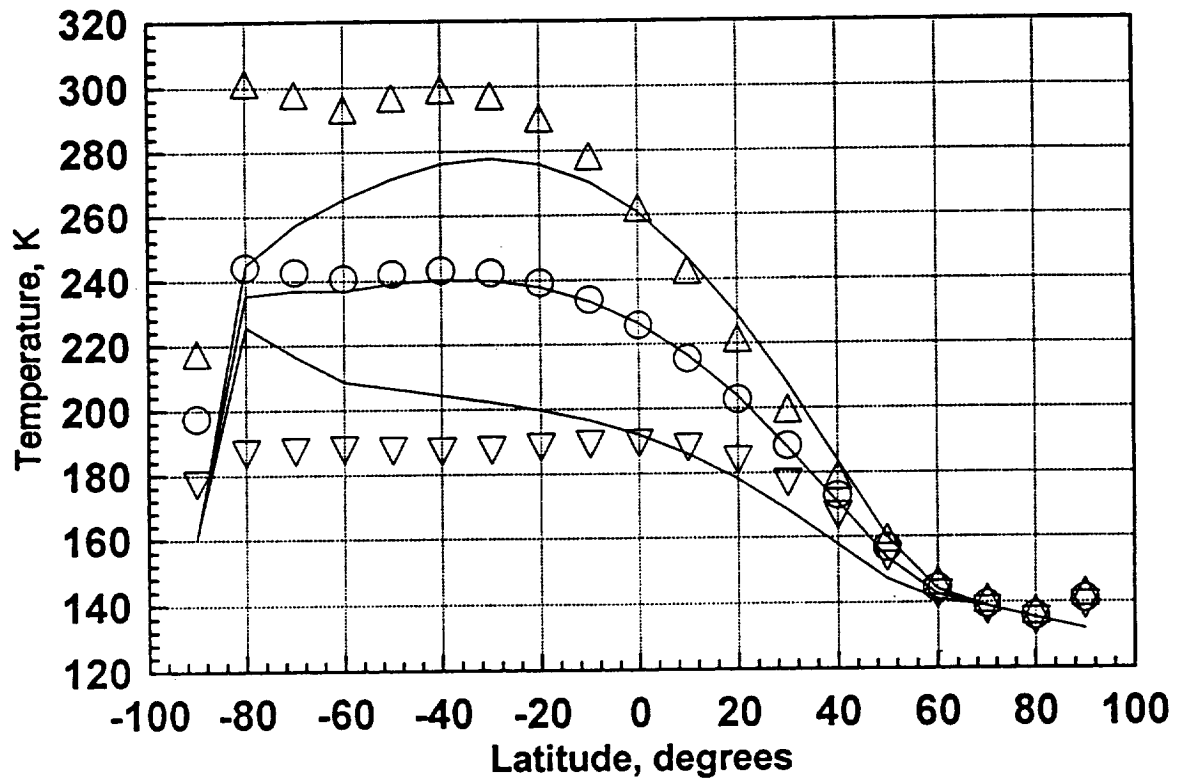


Figure 3-1. Comparison of Old and New Parameterizations for Surface Temperature in MarsGRAM. The season is southern hemisphere summer ( $L_s=270^\circ$ ). Lines are the new regression values for minimum, average and maximum daily surface temperature. Symbols are for the old regression results.

## 4. HOW TO RUN MARS-GRAM

### 4.1 Program Input

Two forms of Mars-GRAM are: interactive, in which values for all input options are provided interactively by the user at run time, and batch, in which values for all input options are provided by a NAMELIST format input file. Table 4-1 illustrates a sample operation of the interactive form of Mars-GRAM version 3.34 and Table 4-2 gives a sample of the NAMELIST file INPUT for the batch form of Mars-GRAM 3.34.

For both the interactive or batch forms, values of the following input variables must be supplied:

LSTFL	Name of LIST file (see Table 4-4). For a listing to the console in interactive form enter filename CON.
OUTFL	Name of OUTPUT file (see Table 4-5).
MONTH	Month (1-12) for initial time
MDAY	Day of the month for initial time
MYEAR	Year for starting time is a 4-digit number. Alternative: input years 1970-2069 as a 2-digit number
NPOS	Maximum number of positions to evaluate to automatically generate a profile. Use 0 if trajectory positions are read in from a TRAJDATA file.
IHR	Initial time, hour of the day GMT
IMIN	Initial time, minute of the hour
SEC	Initial time, second of the minute
ALS0	Value of the areocentric longitude of the Sun (Ls, in degrees) where a dust storm is to start. Use 0 if no dust storm is to be simulated. (Dust storm can be simulated only during the season of the Mars year for Ls between 180 and 320 degrees.)
INTENS	Dust storm intensity, an arbitrary intensity scale, with allowable values from 0.0 (no dust storm) to 3.0 (maximum intensity dust storm). [No prompt occurs in interactive form, if no dust storm is to be simulated (ALS0=0).]

<b>RADMAX</b>	Maximum radius (km) a dust storm attains, developing according to the parameterized space and time profile of build up and decay in the program. If 0 or >10000 km is used, the storm is considered of global dimensions (uniformly covering the planet), but assumed to build up and decay in intensity according to the same temporal profile. [No prompt occurs in interactive, if no dust storm is to be simulated.]
<b>DUSTLAT</b>	Latitude (degrees, North positive) for center of dust storm. [No prompt occurs in interactive, if no dust storm is to be simulated or storm has global dimensions.]
<b>DUSTLON</b>	Longitude (degrees, West positive) for center of dust storm. [No prompt occurs in interactive, if no dust storm is to be simulated or storm has global dimensions.]
<b>F107</b>	10.7-cm solar flux (units $10^{-22}$ W/cm <sup>2</sup> ) at the average Earth orbit position (1 AU). Program automatically converts solar flux to its value at orbit position of Mars.
<b>STDL</b>	Standard deviation parameter for long-term variations in the Stewart model thermosphere. Normal value is 0; allowable range is -3.0 to +3.0.
<b>MODPERT</b>	Model number for perturbations to be computed: 1 is for random (mountain wave) model, 2 is for Zurek (tidal) wave model, and 3 means use combined perturbations from both models.
<b>NR1</b>	Seed value (integer) for random number generator. Allowable range is 1 to 29999. No prompt occurs in interactive if MODPERT = 2. To do Monte Carlo simulations with a variety of perturbations, use a different random number seed on each run. To repeat a given perturbation sequence on a later run, use same random number seed value.
<b>NVARX</b>	x-code for plotable output (x-y pairs for 1-D line graphs or x-y-z triplets for 2-D contour plots). See Table 4-3 for list of variables associated with x-code (e.g., if NVARX = 1, output is for plotting versus height above reference ellipsoid).
<b>NVARY</b>	y-code for 2-D contour plot output (x-y-z triplets). Use y-code 0 for 1-D line graph (x-y pair) plots. See Table 4-3 for list of y-code values and parameters.
<b>LOGSCALE -</b>	Parameter controls units of output values for density and pressure on output plot files. Value 0 means use regular density and pressure units

( $\text{kg/m}^3$  and  $\text{N/m}^2$ ); 1 means output logarithm (base 10) in regular units; and 2 means output percent deviation from COSPAR values.

FLAT	Latitude of initial point to simulate (degrees, North positive)
FLON	Longitude of initial point to simulate (degrees, West positive)
FHGT	Height (km) of initial point to simulate, above reference ellipsoid
DELHGT	Height increment (km) between successive steps in automatically generated profile (positive upward)
DELLAT	Latitude increment (degrees, Northward positive) between successive steps in automatically generated profile
DELLON	Longitude increment (degrees, Westward positive) between successive steps in automatically generated profile
DELTIME	Time increment (seconds) between steps in automatically generated profile

Two auxiliary input files are also required. File HEIGHTS.DAT contains terrain height data array (terrain height, km, above the reference ellipsoid - see explanation in description of subroutine TERRAIN in Appendix A). File COSPAR.DAT contains height profile of COSPAR temperature, density, and pressure values (see explanation in description of COSPAR subroutine in Appendix A).

If the pre-computed trajectory mode is used (NPOS=0), read trajectory data from TRAJDATA file. Each line of TRAJDATA file is a position and time to compute atmospheric parameters. Input lines contain time (seconds, from initial time), height (km, relative to reference ellipsoid), latitude (degrees, North positive), and longitude (degrees, West positive).

For automatically-generated profiles, output continues until the maximum number of positions (NPOS) is reached. For trajectory positions, enter input from TRAJDATA file, output continues until end of the file is reached. For interactive, the program prompts for additional input values for initial date and number of positions. The program is terminated by giving values of 0 for requested input. (See end of Table 4-1).

**Table 4-1. Sample Operation of the Interactive Form of Mars-GRAM 3.34**

```

Mars-GRAM Interactive version 3.34 - November 1, 1995
Enter name for LIST file (CON for console listing):
VIKING1.LST
Enter name for OUTPUT file:
VIKING1.OUT
Enter Month, Day of Month, 4-digit Year, and Max Number Positions
7 20 76 21
Enter initial GMT Time (Hours, Minutes, Seconds)
12 30 0
Ls = 97.0 degrees for this date.
Dust storms can occur between Ls = 180 and Ls = 320.
Enter starting Ls value for dust storm (or 0 for none).
0
Enter mean F10.7 flux at 1AU (nominal value = 150)
and +/- number of std. deviations for thermosphere variation
185 0
Enter perturbation model: 1=random, 2=wave, 3=both
3
Enter Starting Random Number (any positive integer < 30,000)
1001
Select x-code and y-code for plotable output versus desired parameter(s):

Code          Parameter
-----
1  Height (above reference ellipsoid, km)
2  Height (above local terrain, km)
3  Latitude (deg.)
4  West Longitude (deg.)
5  Time from start (Earth seconds)
6  Time from start (Martian Sols)
7  Areocentric Longitude of Sun, Ls (deg.)
8  Hour Angle for Local Time (Mars hours * 15)

Use y-code = 0 for plotable output vs x-code variable only
2 0
For density and pressure data units, enter:
0 for normal (MKS), 1 for log-base-10, 2 for % difference from COSPAR
2
Enter Initial Latitude (deg.), West Longitude (deg.)
22 48
Surface elevation = -.50 km at this location
Enter Initial Height (km)
-0.5
Enter Increments in Height (km), Latitude (deg.), West Longitude (deg.),
and Time (sec.)
10 0 0 0
Computing data.
Enter Month, Day of Month, 4-digit Year, and Max Number Positions
0 0 0 0
Normal Termination

```



**Table 4-2. Sample NAMELIST file INPUT for Batch Form of Mars-GRAM 3.34. Inline comments are appended after the ! symbol. Some FORTRAN compilers do not allow inline comments in NAMELIST data files, in which case they cannot be included in the INPUT. Some FORTRAN compilers use alternate forms of the initial and final lines of the file (e.g. &INPUT for \$INPUT and / for \$END is the form for Microsoft DOS FORTRAN).**

```

$INPUT
  LSTFL   = 'VIKING1.LST',  ! List file name (CON for console listing)
  OUTFL   = 'VIKING1.OUT',  ! Output file name
  MONTH   = 7,              ! month of year
  MDAY    = 20,             ! day of month
  MYEAR    = 76,            ! year (4-digit; 1970-2069 can be 2-digit)
  NPOS     = 21,            ! max # positions to evaluate (0 = read data from file)
  IHR      = 12,            ! GMT hour of day
  IMIN     = 30,            ! minute of hour
  SEC      = 0.0,           ! second of minute (for initial position)
  ALSO     = 0.0,           ! starting Ls value (degrees) for dust storm (0 = none)
  INTENS   = 0.0,           ! dust storm intensity (0.0 - 3.0)
  RADMAX   = 0.0,           ! max. radius (km) of dust storm (0 or >10000 = global)
  DUSTLAT  = 0.0,           ! latitude (deg) for center of dust storm
  DUSTLON  = 0.0,           ! West longitude (deg) for center of dust storm
  F107     = 185.0,         ! 10.7 cm solar flux (10**-22 W/cm**2, at 1 AU)
  STDL     = 0.0,           ! std. dev. for thermosphere variation (-3.0 to +3.0)
  MODPERT  = 3,             ! perturbation model; 1=random, 2=wave, 3=both
  NR1      = 1001,          ! starting random number (0 < NR1 < 30000)
  NVARX    = 2,             ! x-code for plotable output (1=hgt above ref. ellipse)
  NVARY    = 0,             ! y-code for 2-D plotable output (0 for 1-D plots)
  LOGSCALE = 0,             ! 0=regular density, 1=log(density), 2=COSPAR deviations
  FLAT     = 22.0,          ! initial latitude (N positive), degrees
  FLON     = 48.0,          ! initial longitude (West positive), degrees
  FHGT     = -0.5,          ! initial height (km), above ref. ellipse
  DELHGT   = 10.0,          ! height increment (km) between steps
  DELLAT   = 0.0,           ! latitude increment (deg) between steps
  DELLON   = 0.0,           ! West longitude increment (deg) between steps
  DELTIME  = 0.0,           ! time increment (sec) between steps
$END

```

**Table 4-3. List of x-code and y-code Values and Parameters for Platable Output  
(graphics) Files**

Code	Parameter	
-----	-----	SETU283
1	Height (above reference ellipsoid, km)	SETU284
2	Height (above local terrain, km)	SETU285
3	Latitude (deg.)	SETU286
4	West Longitude (deg.)	SETU287
5	Time from start (Earth seconds)	SETU288
6	Time from start (Martian Sols)	SETU289
7	Areocentric Longitude of Sun, Ls (deg.)	SETU290
8	Hour Angle for Local Time (Mars hours * 15)	SETU291
		SETU292
Use y-code = 0 for plotable output vs x-code variable only		SETU293

## 4.2 Program Output

Three general types of program output are: (1) a "LIST" file, containing header and descriptor information, suitable for printing or viewing by an analyst (LIST file, Table 4-4), (2) "OUTPUT" file, containing no header or descriptor information, one line per output position, suitable for reading into another program for additional analysis (OUTPUT file, in Table 4-5), and (3) set of "plotable" output files, suitable for input to a graphics program (Table 4-6).

Plot output files contain either x-y data pairs or x-y-z data triplets, determined from selected values for x-code (NVARX) and y-code (NVARY). If 1-D line-graph (x-y pair) data is the selected plot output option (y-code = 0), then the x-code variable normally appears first in the output pair. However, if the x-code variable selected for plot output is a height variable (x-code = 1 or 2) then the plot output values give the height as the second variable of the output pair. This facilitates graphs with height as the ordinate, since many graphics programs expect input data pairs in abscissa-ordinate order. If 2-D contour plot (x-y-z triplet) data is the selected plot output option (y-code  $\neq$  0), then the plot output variables always appear as: x-code variable, y-code variable, plot output variable. See Table 4-7 for list of plot output variables generated and associated file unit numbers (plot output files are unit numbers 21 through 28 and 30 through 34).

Table 4-7 gives the unit numbers for all program input and output files. With the exception of the screen output and the TRAJDATA input file, the program input and output files are also referred to within the program by a FILES array. The FILES array index values associated with the program input and output files are also shown in Table 4-7.

If the user desires to suppress the LIST, OUTPUT, and plotable output files (to handle output in a user-provided program), set the LIST file unit number (iup) to 0 (line BLKD 15, in BLOCK DATA routine in MARSSUBS.FOR file) and re-compile the program. The unit number associated with "screen" output (iu0), normally 6, is set to any other value by changing it at line BLKD 16 and re-compiling the program.

WRITE statements and output FORMATS used to produce the OUTPUT file are shown in the following code lines from the DATASTEP subroutine (in MARSSUBS.FOR file):

<code>If(logscale.eq.0)Then</code>	<code>DSTP346b</code>
<code>WRITE(29,800)CSEC,VAR,CLAT,CLON,dens,TEMP,EWWIND,</code>	<code>DSTP347</code>
<code>&amp; NSWIND,SIGD,DENSWA,ALS</code>	<code>DSTP348</code>
<code>Else</code>	<code>DSTP348a</code>
<code>WRITE(29,810)CSEC,VAR,CLAT,CLON,dens,TEMP,EWWIND,</code>	<code>DSTP348b</code>
<code>&amp; NSWIND,SIGD,DENSWA,ALS</code>	<code>DSTP348c</code>
<code>Endif</code>	<code>DSTP348d</code>
<code>Endif</code>	<code>DSTP348e</code>

```

800 FORMAT(F10.0,3F7.2,1PE9.2,0P3F7.1,3F6.1)
810 FORMAT(F10.0,3F7.2,F9.2,3F7.1,3F6.1)

```

**DSTP349**  
**DSTP349a**

If other variables or output formats are desired, alter appropriate program lines and re-compile the program.

The output data, some echoed from input values for a record of the options selected, are illustrated by the sample LIST file in Table 4-4. Output variables and descriptions are as follows:

MONTH, MDAY, MYEAR, IHR, IMIN, SEC, ALS0, INTENS, RADMAX, DUSTLAT, DUSTLON, F107, STDL, MODPERT, and NR1 are defined in Section 4.1.

DATE	Julian date, computed from input year, month and day
CSEC	Time (seconds) from start of simulation [also units of Mars days (sols)]
ALS	Areocentric longitude of the Sun (Ls) in degrees (angle at Mars analogous to right ascension of the Sun for the Earth)
OHGT	Height above reference ellipsoid (km)
OHGTS	Height above local terrain (km) (shown in parentheses in LIST file output)
HSCALE	Pressure scale height (km)
CLAT	Current latitude (positive North)
CLON	Current longitude (positive West)
SUNLON	Mars longitude of sub-solar point (degrees)
TLOCAL	Local solar time (in Mars hours, 1/24th sols)
TEMP	Temperature (K) at current location (also output to plot file TEMP, unit 25, Table 4-7)
PRES	Pressure ( $\text{N/m}^2$ ) at current location (also output to plot file PRES, unit 26, Table 4-7; units in plot file controlled by LOGSCALE option)
DENSLO	Low (approximately -1 standard deviation) density ( $\text{kg/m}^3$ ) at current location (also output to plot file DENSLO, unit 33, Table 4-7; units in plot file controlled by LOGSCALE option)

<b>DENS</b>	Average density ( $\text{kg/m}^3$ ) at current location (also output to plot file DENS <sub>AV</sub> , unit 22, Table 4-7; units in plot file controlled by LOGSCALE option)
<b>DENSHI</b>	High (approximately +1 standard deviation) density ( $\text{kg/m}^3$ ) at current location (also output to plot file DENS <sub>HI</sub> , unit 34, Table 4-7; units in plot file controlled by LOGSCALE option)
<b>DEVLO</b>	Low density expressed as percentage deviation from COSPAR value
<b>DEVAV</b>	Average density expressed as percentage deviation from COSPAR value
<b>DEVHI</b>	High density expressed as percentage deviation from COSPAR value
<b>DENSP</b>	Density perturbation (relative to mean value), expressed as percentage of mean (also output to plot file DENS <sub>RP</sub> , unit 24, Table 4-7).
<b>EWWIND</b>	Eastward wind component (m/s) (also output to plot file EWWIND, unit 27, Table 4-7).
<b>NSWIND</b>	Northward wind component (m/s) (also output to plot file NSWIND, unit 28, Table 4-7).

Other variables not output to LIST file but output to plot files (may be selected for output to OUTPUT file) are the following:

<b>SIGD</b>	Standard deviation of density perturbations (percent of mean value) (output to plot file DENS <sub>RM</sub> , unit 21, Table 4-7)
<b>DENSWA</b>	Value of the Zurek wave model density perturbation (percent of mean value) (output to plot file DENS <sub>WA</sub> , unit 23, Table 4-7)
<b>TMAX</b>	Daily maximum temperature (K) at surface, for current location (output to plot file TMAX, unit 30, Table 4-7)
<b>TMIN</b>	Daily minimum temperature (K) at surface, for current location (output to plot file TMIN, unit 31, Table 4-7)
<b>TAVG</b>	Daily average temperature (K) at surface, for current location (output to plot file TAVG, unit 32, Table 4-7)

**Table 4-4. LIST file (VIKING1.LST) Produced by Either Interactive or Batch Form  
(Page 1 of 4)**

```

Mars-GRAM Version 3.34 Interactive Form - November 1, 1995
Date = 7/20/1976 Julian Date = 2442980.0 GMT Time = 12:30: .0
Fl0.7 flux = 185.0 (1 AU) 68.1 (Mars), standard deviation = .0
Perturbation model = 3 Starting random number = 1001
Time (rel. to T0) = .0 sec. ( .000 sols) Ls = 97.0 deg.
Height = -.50 km ( .00 km) Scale Height = 12.48 km
Latitude = 22.000 degrees West Longitude = 48.000 degrees
Sun Longitude = 111.188 deg. Local Time = 16.21 Mars hours
Temperature = 243.4 K Pressure = 7.478E+02 N/m**2
Density (Low, Avg., High) = 1.502E-02 1.607E-02 1.712E-02 kg/m**3
Departure, COSPAR NH Mean = -7.5 % -1.0 % 5.5 %
Density perturbation = 8.76 % of mean value
Eastward Wind = 4.3 m/s Northward Wind = -.3 m/s
-----
Time (rel. to T0) = .0 sec. ( .000 sols) Ls = 97.0 deg.
Height = 9.50 km ( 10.00 km) Scale Height = 10.39 km
Latitude = 22.000 degrees West Longitude = 48.000 degrees
Sun Longitude = 111.188 deg. Local Time = 16.21 Mars hours
Temperature = 202.7 K Pressure = 3.055E+02 N/m**2
Density (Low, Avg., High) = 7.619E-03 7.884E-03 8.152E-03 kg/m**3
Departure, COSPAR NH Mean = 12.9 % 16.8 % 20.8 %
Density perturbation = -1.30 % of mean value
Eastward Wind = 1.3 m/s Northward Wind = -5.5 m/s
-----
Time (rel. to T0) = .0 sec. ( .000 sols) Ls = 97.0 deg.
Height = 19.50 km ( 20.00 km) Scale Height = 9.49 km
Latitude = 22.000 degrees West Longitude = 48.000 degrees
Sun Longitude = 111.188 deg. Local Time = 16.21 Mars hours
Temperature = 185.1 K Pressure = 1.122E+02 N/m**2
Density (Low, Avg., High) = 3.038E-03 3.172E-03 3.309E-03 kg/m**3
Departure, COSPAR NH Mean = 10.2 % 15.0 % 20.0 %
Density perturbation = -1.41 % of mean value
Eastward Wind = -1.8 m/s Northward Wind = -9.0 m/s
-----
Time (rel. to T0) = .0 sec. ( .000 sols) Ls = 97.0 deg.
Height = 29.50 km ( 30.00 km) Scale Height = 8.72 km
Latitude = 22.000 degrees West Longitude = 48.000 degrees
Sun Longitude = 111.188 deg. Local Time = 16.21 Mars hours
Temperature = 170.2 K Pressure = 3.800E+01 N/m**2
Density (Low, Avg., High) = 1.096E-03 1.168E-03 1.242E-03 kg/m**3
Departure, COSPAR NH Mean = 6.0 % 13.0 % 20.1 %
Density perturbation = -.30 % of mean value
Eastward Wind = -4.8 m/s Northward Wind = -13.9 m/s
-----
Time (rel. to T0) = .0 sec. ( .000 sols) Ls = 97.0 deg.
Height = 39.50 km ( 40.00 km) Scale Height = 8.19 km
Latitude = 22.000 degrees West Longitude = 48.000 degrees
Sun Longitude = 111.188 deg. Local Time = 16.21 Mars hours
Temperature = 159.8 K Pressure = 1.192E+01 N/m**2
Density (Low, Avg., High) = 3.655E-04 3.903E-04 4.160E-04 kg/m**3
Departure, COSPAR NH Mean = 1.8 % 8.7 % 15.9 %
Density perturbation = -.32 % of mean value
Eastward Wind = -8.2 m/s Northward Wind = -20.1 m/s
-----
Time (rel. to T0) = .0 sec. ( .000 sols) Ls = 97.0 deg.
Height = 49.50 km ( 50.00 km) Scale Height = 7.67 km
Latitude = 22.000 degrees West Longitude = 48.000 degrees
Sun Longitude = 111.188 deg. Local Time = 16.21 Mars hours
Temperature = 149.6 K Pressure = 3.488E+00 N/m**2
Density (Low, Avg., High) = 1.103E-04 1.220E-04 1.340E-04 kg/m**3
Departure, COSPAR NH Mean = -4.0 % 6.3 % 16.8 %

```

**Table 4-4. LIST file (VIKING1.LST) Produced by Either Interactive or Batch Form  
(Page 2 of 4)**

Density perturbation =	5.36 % of mean value		
Eastward Wind =	-11.9 m/s	Northward Wind =	-26.7 m/s
-----			
Time (rel. to T0) =	.0 sec. (	.000 sols)	Ls = 97.0 deg.
Height = 59.50 km ( 60.00 km)	Scale Height =	7.39 km	
Latitude = 22.000 degrees	West Longitude =	48.000 degrees	
Sun Longitude = 111.188 deg.	Local Time =	16.21 Mars hours	
Temperature = 144.1 K	Pressure =	9.618E-01 N/m**2	
Density (Low, Avg., High) =	3.018E-05	3.491E-05	3.973E-05 kg/m**3
Departure, COSPAR NH Mean =	-10.9 %	3.0 %	17.3 %
Density perturbation =	-9.27 % of mean value		
Eastward Wind =	-16.2 m/s	Northward Wind =	-33.9 m/s
-----			
Time (rel. to T0) =	.0 sec. (	.000 sols)	Ls = 97.0 deg.
Height = 69.50 km ( 70.00 km)	Scale Height =	7.13 km	
Latitude = 22.000 degrees	West Longitude =	48.000 degrees	
Sun Longitude = 111.188 deg.	Local Time =	16.21 Mars hours	
Temperature = 139.0 K	Pressure =	2.552E-01 N/m**2	
Density (Low, Avg., High) =	8.298E-06	9.599E-06	1.092E-05 kg/m**3
Departure, COSPAR NH Mean =	-11.1 %	2.9 %	17.1 %
Density perturbation =	-1.71 % of mean value		
Eastward Wind =	-20.7 m/s	Northward Wind =	-39.8 m/s
-----			
Time (rel. to T0) =	.0 sec. (	.000 sols)	Ls = 97.0 deg.
Height = 79.50 km ( 80.00 km)	Scale Height =	7.34 km	
Latitude = 22.000 degrees	West Longitude =	48.000 degrees	
Sun Longitude = 111.188 deg.	Local Time =	16.21 Mars hours	
Temperature = 136.5 K	Pressure =	5.487E-02 N/m**2	
Density (Low, Avg., High) =	1.680E-06	2.100E-06	2.549E-06 kg/m**3
Departure, COSPAR NH Mean =	-31.4 %	-14.3 %	4.1 %
Density perturbation =	3.65 % of mean value		
Eastward Wind =	-23.7 m/s	Northward Wind =	-40.5 m/s
-----			
Time (rel. to T0) =	.0 sec. (	.000 sols)	Ls = 97.0 deg.
Height = 89.50 km ( 90.00 km)	Scale Height =	7.55 km	
Latitude = 22.000 degrees	West Longitude =	48.000 degrees	
Sun Longitude = 111.188 deg.	Local Time =	16.21 Mars hours	
Temperature = 139.2 K	Pressure =	8.699E-03 N/m**2	
Density (Low, Avg., High) =	2.227E-07	3.256E-07	4.505E-07 kg/m**3
Departure, COSPAR NH Mean =	-65.3 %	-49.3 %	-29.9 %
Density perturbation =	-31.47 % of mean value		
Eastward Wind =	-22.0 m/s	Northward Wind =	-31.5 m/s
-----			
Time (rel. to T0) =	.0 sec. (	.000 sols)	Ls = 97.0 deg.
Height = 99.50 km ( 100.00 km)	Scale Height =	7.90 km	
Latitude = 22.000 degrees	West Longitude =	48.000 degrees	
Sun Longitude = 111.188 deg.	Local Time =	16.21 Mars hours	
Temperature = 144.4 K	Pressure =	1.470E-03 N/m**2	
Density (Low, Avg., High) =	3.083E-08	5.284E-08	8.334E-08 kg/m**3
Departure, COSPAR NH Mean =	-81.9 %	-68.9 %	-51.0 %
Density perturbation =	-7.08 % of mean value		
Eastward Wind =	-18.3 m/s	Northward Wind =	-21.2 m/s
-----			
Time (rel. to T0) =	.0 sec. (	.000 sols)	Ls = 97.0 deg.
Height = 109.50 km ( 110.00 km)	Scale Height =	8.44 km	
Latitude = 22.000 degrees	West Longitude =	48.000 degrees	
Sun Longitude = 111.188 deg.	Local Time =	16.21 Mars hours	
Temperature = 152.9 K	Pressure =	2.776E-04 N/m**2	
Density (Low, Avg., High) =	4.922E-09	9.394E-09	1.618E-08 kg/m**3
Departure, COSPAR NH Mean =	-88.9 %	-78.7 %	-63.4 %
Density perturbation =	128.57 % of mean value		
Eastward Wind =	-11.5 m/s	Northward Wind =	-9.8 m/s
-----			

**Table 4-4. LIST file (VIKING1.LST) Produced by Either Interactive or Batch Form  
(Page 3 of 4)**

Time (rel. to T0) =	.0 sec. (	.000 sols)	Ls =	97.0 deg.
Height = 119.50 km ( 120.00 km)	Scale Height =	11.18 km		
Latitude = 22.000 degrees	West Longitude =	48.000 degrees		
Sun Longitude = 111.188 deg.	Local Time =	16.21 Mars hours		
Temperature = 199.8 K	Pressure =	7.618E-05 N/m**2		
Density (Low, Avg., High) =	1.317E-09	1.959E-09	2.886E-09	kg/m**3
Departure, COSPAR NH Mean =	-89.6 %	-84.5 %	-77.2 %	
Density perturbation =	-17.49 % of mean value			
Eastward Wind = -4.4 m/s	Northward Wind =	-3.2 m/s		
-----				
Time (rel. to T0) =	.0 sec. (	.000 sols)	Ls =	97.0 deg.
Height = 129.50 km ( 130.00 km)	Scale Height =	14.53 km		
Latitude = 22.000 degrees	West Longitude =	48.000 degrees		
Sun Longitude = 111.188 deg.	Local Time =	16.21 Mars hours		
Temperature = 255.1 K	Pressure =	3.512E-05 N/m**2		
Density (Low, Avg., High) =	4.979E-10	6.990E-10	9.288E-10	kg/m**3
Departure, COSPAR NH Mean =	-87.5 %	-82.4 %	-76.6 %	
Density perturbation =	1.15 % of mean value			
Eastward Wind = -2.0 m/s	Northward Wind =	-2.8 m/s		
-----				
Time (rel. to T0) =	.0 sec. (	.000 sols)	Ls =	97.0 deg.
Height = 139.50 km ( 140.00 km)	Scale Height =	16.60 km		
Latitude = 22.000 degrees	West Longitude =	48.000 degrees		
Sun Longitude = 111.188 deg.	Local Time =	16.21 Mars hours		
Temperature = 285.8 K	Pressure =	1.851E-05 N/m**2		
Density (Low, Avg., High) =	2.262E-10	3.241E-10	4.298E-10	kg/m**3
Departure, COSPAR NH Mean =	-80.3 %	-71.8 %	-62.6 %	
Density perturbation =	1.73 % of mean value			
Eastward Wind = -.8 m/s	Northward Wind =	-1.7 m/s		
-----				
Time (rel. to T0) =	.0 sec. (	.000 sols)	Ls =	97.0 deg.
Height = 149.50 km ( 150.00 km)	Scale Height =	18.01 km		
Latitude = 22.000 degrees	West Longitude =	48.000 degrees		
Sun Longitude = 111.188 deg.	Local Time =	16.21 Mars hours		
Temperature = 302.9 K	Pressure =	1.039E-05 N/m**2		
Density (Low, Avg., High) =	1.124E-10	1.687E-10	2.300E-10	kg/m**3
Departure, COSPAR NH Mean =	-77.1 %	-65.7 %	-53.2 %	
Density perturbation =	37.30 % of mean value			
Eastward Wind = -.4 m/s	Northward Wind =	-1.0 m/s		
-----				
Time (rel. to T0) =	.0 sec. (	.000 sols)	Ls =	97.0 deg.
Height = 159.50 km ( 160.00 km)	Scale Height =	19.10 km		
Latitude = 22.000 degrees	West Longitude =	48.000 degrees		
Sun Longitude = 111.188 deg.	Local Time =	16.21 Mars hours		
Temperature = 312.5 K	Pressure =	6.064E-06 N/m**2		
Density (Low, Avg., High) =	5.869E-11	9.339E-11	1.324E-10	kg/m**3
Departure, COSPAR NH Mean =	-76.6 %	-62.8 %	-47.2 %	
Density perturbation =	-35.75 % of mean value			
Eastward Wind = -.3 m/s	Northward Wind =	-.5 m/s		
-----				
Time (rel. to T0) =	.0 sec. (	.000 sols)	Ls =	97.0 deg.
Height = 169.50 km ( 170.00 km)	Scale Height =	20.07 km		
Latitude = 22.000 degrees	West Longitude =	48.000 degrees		
Sun Longitude = 111.188 deg.	Local Time =	16.21 Mars hours		
Temperature = 317.9 K	Pressure =	3.638E-06 N/m**2		
Density (Low, Avg., High) =	3.170E-11	5.362E-11	7.946E-11	kg/m**3
Departure, COSPAR NH Mean =	-77.2 %	-61.4 %	-42.8 %	
Density perturbation =	-8.43 % of mean value			
Eastward Wind = -.2 m/s	Northward Wind =	-.3 m/s		
-----				
Time (rel. to T0) =	.0 sec. (	.000 sols)	Ls =	97.0 deg.
Height = 179.50 km ( 180.00 km)	Scale Height =	21.06 km		
Latitude = 22.000 degrees	West Longitude =	48.000 degrees		



**Table 4-4. LIST file (VIKING1.LST) Produced by Either Interactive or Batch Form  
(Page 4 of 4)**

Sun Longitude = 111.188 deg.	Local Time = 16.21 Mars hours
Temperature = 321.0 K	Pressure = 2.236E-06 N/m**2
Density (Low, Avg., High) =	1.757E-11 3.158E-11 4.897E-11 kg/m**3
Departure, COSPAR NH Mean =	-78.3 % -61.1 % -39.6 %
Density perturbation =	-.26 % of mean value
Eastward Wind = -.2 m/s	Northward Wind = -.1 m/s
-----	
Time (rel. to T0) = .0 sec. ( .000 sols)	Ls = 97.0 deg.
Height = 189.50 km ( 190.00 km)	Scale Height = 22.15 km
Latitude = 22.000 degrees	West Longitude = 48.000 degrees
Sun Longitude = 111.188 deg.	Local Time = 16.21 Mars hours
Temperature = 322.7 K	Pressure = 1.407E-06 N/m**2
Density (Low, Avg., High) =	9.968E-12 1.899E-11 3.078E-11 kg/m**3
Departure, COSPAR NH Mean =	-79.5 % -60.9 % -36.7 %
Density perturbation =	-3.07 % of mean value
Eastward Wind = -.1 m/s	Northward Wind = -.1 m/s
-----	
Time (rel. to T0) = .0 sec. ( .000 sols)	Ls = 97.0 deg.
Height = 199.50 km ( 200.00 km)	Scale Height = 23.43 km
Latitude = 22.000 degrees	West Longitude = 48.000 degrees
Sun Longitude = 111.188 deg.	Local Time = 16.21 Mars hours
Temperature = 323.7 K	Pressure = 9.066E-07 N/m**2
Density (Low, Avg., High) =	5.795E-12 1.164E-11 1.967E-11 kg/m**3
Departure, COSPAR NH Mean =	-80.6 % -61.1 % -34.3 %
Density perturbation =	-4.85 % of mean value
Eastward Wind = -.1 m/s	Northward Wind = .0 m/s
-----	

**Table 4-5. OUTPUT file (VIKING1.OUT) Produced by Either Interactive or Batch Form (Heading added for readability)**

Time	Hgt	Lat	Lon	Dens %COSPAR	Temp	EWind	Nwind	Dev	Wave	Ls
0.	.00	22.00	48.00	-1.00	243.4	4.3	-.3	.9	5.6	97.0
0.	10.00	22.00	48.00	16.80	202.7	1.3	-5.5	1.9	1.5	97.0
0.	20.00	22.00	48.00	15.05	185.1	-1.8	-9.0	2.9	1.4	97.0
0.	30.00	22.00	48.00	13.01	170.2	-4.8	-13.9	3.9	2.4	97.0
0.	40.00	22.00	48.00	8.71	159.8	-8.2	-20.1	4.8	1.6	97.0
0.	50.00	22.00	48.00	6.27	149.6	-11.9	-26.7	4.9	4.9	97.0
0.	60.00	22.00	48.00	3.04	144.1	-16.2	-33.9	4.9	8.8	97.0
0.	70.00	22.00	48.00	2.89	139.0	-20.7	-39.8	4.9	8.8	97.0
0.	80.00	22.00	48.00	-14.28	136.5	-23.7	-40.5	11.9	8.8	97.0
0.	90.00	22.00	48.00	-49.33	139.2	-22.0	-31.5	26.2	8.8	97.0
0.	100.00	22.00	48.00	-68.94	144.4	-18.3	-21.2	40.9	8.8	97.0
0.	110.00	22.00	48.00	-78.75	152.9	-11.5	-9.8	51.1	8.8	97.0
0.	120.00	22.00	48.00	-84.54	199.8	-4.4	-3.2	31.2	8.8	97.0
0.	130.00	22.00	48.00	-82.41	255.1	-2.0	-2.8	22.0	8.8	97.0
0.	140.00	22.00	48.00	-71.78	285.8	-.8	-1.7	22.6	8.8	97.0
0.	150.00	22.00	48.00	-65.68	302.9	-.4	-1.0	26.1	8.8	97.0
0.	160.00	22.00	48.00	-62.78	312.5	-.3	-.5	30.7	8.8	97.0
0.	170.00	22.00	48.00	-61.41	317.9	-.2	-.3	35.7	8.8	97.0
0.	180.00	22.00	48.00	-61.06	321.0	-.2	-.1	40.9	8.8	97.0
0.	190.00	22.00	48.00	-60.94	322.7	-.1	-.1	46.0	8.8	97.0
0.	200.00	22.00	48.00	-61.10	323.7	-.1	.0	50.8	8.8	97.0

**Table 4-6. Sample Platable Output File (DENSAY) [first variable = average density  
(% COSPAR difference), second variable = height]**

-.9976	.0000
16.80	10.00
15.05	20.00
13.01	30.00
8.714	40.00
6.274	50.00
3.039	60.00
2.891	70.00
-14.28	80.00
-49.33	90.00
-68.94	100.0
-78.75	110.0
-84.54	120.0
-82.41	130.0
-71.78	140.0
-65.68	150.0
-62.78	160.0
-61.41	170.0
-61.06	180.0
-60.94	190.0
-61.10	200.0

**Table 4-7. File Names Used in the Mars-GRAM Programs**

FILES Array Index -----	File Name (description of file) -----	Unit Number -----
1	LSTFL (default name = LIST)	iup (default=11 BLKD 15) Set to 0 to suppress LIST and graphics file output
2	DENSRM (std. deviation in density)	21
3	DENSAV (average density)	22
4	DENSWA (wave model perturbations)	23
5	DENSRP (random perturbations)	24
6	TEMP (temperatures)	25
7	PRES (pressure)	26
8	EWIND (eastward wind component)	27
9	NSWIND (northward wind component)	28
10	OUTFL (default name = OUTPUT)	29
11	HEIGHTS.DAT (terrain heights)	9
12	TMAX (daily max. surf. temp.)	30
13	TMIN (daily min. surf. temp.)	31
14	TAVG (daily avg. surf. temp.)	32
15	DENSLO (low density, -1 sigma)	33
16	DENSHI (high density, +1 sigma)	34
17	COSPAR.DAT (COSPAR data arrays)	10
N/A	TRAJDATA (trajectory input)	7
N/A	Unnamed screen output	iu0 (default=6 BLKD 16)

## 4.3 How to Use Mars-GRAM Batch Form as Subroutines in Other Programs

Stripped of all embedded comment statements, the batch form program (MARSGRMB.FOR) consists of the following lines of code:

```
DOUBLE PRECISION DATE0
Real NSWIND
Integer EOF
Call Setup(CHGT,CLAT,CLON,CSEC,DATE0,RHO,DELHGT,DELLAT,DELLON,
& DELTIME,MAXNUM)
DO 900 I = 0,MAXNUM
    Call Datastep(I,CHGT,CLAT,CLON,CSEC,DATE0,RHO,EOF,DELHGT,
& DELLAT,DELLON,DELTIME,TEMP,PRES,DENSLO,DENS,DENSHI,DENSP,
& EWWIND,NSWIND)
    If (EOF .eq. 1)Goto 999
900 Continue
999 STOP ' Normal Termination'
END
```

All variables are initialized through SETUP subroutine which must be called once at beginning of program. Atmospheric parameters are evaluated at successive locations (either trajectory or automatic profile mode) with DATASTEP subroutine. Any desired output (or transfer to other subroutines) is done within the loop that calls DATASTEP (i.e. just after "Call Datastep" statement). To suppress the normal LIST, OUTPUT, and graphics file output, set iup=0 at line BLKD 15 in the BLOCK DATA routine (in the MARSSUBS.FOR file).

To embed SETUP and DATASTEP subroutines into a program that computes trajectory or orbit positions, the calling program keeps current position updated (height CHGT, latitude CLAT, longitude CLON, at time after start of the run CSEC) and computes velocity components from which displacements in height, latitude, and longitude can be computed for any desired time step.

A program using SETUP and DATASTEP as subroutines takes the following form (added pseudo-code is shown in brackets):

```
DOUBLE PRECISION DATE0
Real NSWIND
Integer EOF
Call Setup(CHGT,CLAT,CLON,CSEC,DATE0,RHO,DELHGT,DELLAT,DELLON,
& DELTIME,MAXNUM)

[Comment: Evaluate the atmospheric parameters at the initial
position by calling Datastep with I=0, so that the current
position is not updated.]

Call Datastep(0,CHGT,CLAT,CLON,CSEC,DATE0,RHO,EOF,DELHGT,
& DELLAT,DELLON,DELTIME,TEMP,PRES,DENSLO,DENS,DENSHI,DENSP,
& EWWIND,NSWIND)

100 Continue

[Use the vertical velocity in the trajectory to compute the
height displacement, DELHGT, the north-south velocity to
compute the latitude displacement, DELLAT, and the east-west
velocity to compute the longitude displacement, DELLON, based
on the desired time displacement, DELTIME. These displacement
values will override the values initially defined in the
SETUP routine]

Call Datastep(1,CHGT,CLAT,CLON,CSEC,DATE0,RHO,EOF,DELHGT,
```

```
& DELLAT,DELLON,DELTIME,TEMP,PRES,DENSLO,DENS,DENSHI,DENSP,  
& EWWIND,NSWIND)
```

[Comment: With  $I \neq 0$  in the call to Datastep, the position is updated by the position displacements, before the new atmospheric parameters are evaluated.]

[Write out the current position (CHGT, CLAT, CLON), as it has been updated by Datastep, along with any other output desired. Any other desired analysis of the variables at the current position can also be done here in the program.]

[If the last position and time has been computed, go to 999. Otherwise, go to 100.]

```
999 STOP ' Normal Termination'  
END
```

## 5. DIAGNOSTIC AND PROGRESS MESSAGES

### 5.1 Interactive Form Main Program Mars-GRAM

The interactive form Mars-GRAM main program prompts the user for input options. Some prompt statements provide legal values that can be acceptable for the prompted input option. If the program repeats the prompt message after entered input, a value outside the legal range was input. Corrective action is to input a value within the legal range. Prompt message ceases and operation continues.

Other specific diagnostic or progress messages follow. All STOP messages and messages written to unit iu0 normally appear on the interactive user screen (default value for iu0 is 6, set at line BLKD 16 in BLOCK DATA).

-----

Code Producing the Message:

```
50      Write(iu0,60)files(j),ierr(j)                                MARS108
60      Format(1x,a12,' File open error! Error =',i5)                MARS109
```

Purpose:

To indicate an error occurred in attempt to open one of the 17 files in FILES array (see Table 4-7 for file names). Message gives file name and error code that caused the (first encountered) problem.

Remedy:

Depending on meaning of error code on compiler system, take appropriate corrective action to ensure proper file open operation. Rerun program.

-----

Code Producing the Message:

```
65 Stop ' Error or EOF on COSPAR.DAT file!'                          MARS112g
```

Purpose:

To indicate an End-of-File or read error occurred on COSPAR.DAT file (file may not exist or path to this file may not be set appropriately).

Remedy:

Correct error condition (i.e., copy or restore file to right location). Rerun program.

---

Code Producing the Message:

```
80 If (lat .ne. -100+10*i) Stop ' Error reading HEIGHTS.DAT!' MARS116
```

Purpose:

To indicate a latitude read from HEIGHTS.DAT file was an unexpected value (file is missing, corrupted, or sized wrong based on parameters nlat and nlon).

Remedy:

Correct problem with HEIGHTS.DAT file. Rerun program.

---

Code Producing the Message:

```
260 Write(iu0)270 MARS144
270 format(' Unable to open Trajectory Data file!') MARS145
```

Purpose:

To indicate an error occurred in attempt to open trajectory input data file TRAJDATA (file may not exist or may have wrong path set to its location).

Remedy:

Correct problem with TRAJDATA file. Rerun program.

---



### Code Producing the Message:

```
      if (als0 .gt. 0.) Write(iu0,*) ' Ls outside range. ',  
&      ' No dust storm assumed.'
```

**MARS177**  
**MARS178**

### Purpose:

To indicate user attempted to simulate a dust storm for a value of areocentric longitude of the Sun (Ls) outside range 180 to 320. Message reminds user that dust storms cannot be simulated for Ls values outside this range and no dust storm is being simulated during the run.

### Remedy:

None necessarily required. If a dust storm case is desired, select a different Ls ( $180 < Ls < 320$ ). Rerun program.

-----

### Code Producing the Message:

```
      Write(iu0,*) ' Intensity must be between 0 and 3'
```

**MARS187**

### Purpose:

To indicate a dust storm intensity  $< 0.0$  or  $> 3.0$  was entered.

### Remedy:

Input a dust storm intensity between 0.0 and 3.0. Rerun program.

-----

### Code Producing the Message:

```
      Write(iu0,*) ' F10.7 must be between 50 and 450'
```

**MARS213**

### Purpose:

To indicate an F10.7 solar flux  $< 50$  or  $> 450$  was entered.

Remedy:

Input an F10.7 value between 50 and 450. Rerun program.

---

Code Producing the Message:

```
Write(iu0,*)' Std. deviations must be between -3 and +3' MARS217
```

Purpose:

To indicate a standard deviation in the Stewart thermosphere model < -3 or > +3 was entered (nominal value is 0.0).

Remedy:

Input a standard deviation value between -3 and +3. Rerun program.

---

Code Producing the Message:

```
430 Write(iu0,440) MARS312
440 FORMAT(' Computing data.') MARS313
```

Purpose:

To indicate all data are input successfully and computations underway.

Remedy:

Complete the run. Time required depends on size of trajectory input file or number of automatic profile positions to be computed.

---

Code Producing the Message:

**9998 Stop ' Error termination on opening or reading input file' MARS323**

Purpose:

To indicate a termination message if file open error occurred on trajectory file or other files in FILES array.

Remedy:

Correct file problem, according to preceding error message. Rerun program.

-----

Code Producing the Message:

**9999 STOP ' Normal Termination' MARS324**

Purpose:

To indicate successful completion of program run.

Remedy:

None required.

-----

## 5.2 Batch Form Main Program MARSGRMB

The batch form Marsgrmb main program does not produce diagnostic or progress messages other than the normal termination message for output to the STOP messages location.

---

### Code Producing the Message:

999 STOP ' Normal Termination'

MARB117

### Purpose:

To indicate successful completion of program run.

### Remedy:

None required.

---

### 5.3 Subroutine SETUP

Several diagnostic or progress messages are produced by the SETUP subroutine. SETUP is called by the batch form only (not the interactive form) of the program.

---

Code Producing the Message:

```
50      Write(iu0,60)files(j),ierr(j)                      SETU141
60      Format(1x,a12,' File open error! Error =',i5)      SETU142
```

Purpose:

To indicate an error occurred in attempt to open one of the 17 files in FILES array (see separate Table 4-7 for file names). Message gives file name and error code that caused the (first encountered) problem.

Remedy:

Depending on meaning of error code on compiler system, take appropriate corrective action to ensure proper file open operation. Rerun program.

---

Code Producing the Message:

```
65 Stop ' Error or EOF on COSPAR.DAT file!'                SETU146g
```

Purpose:

To indicate an End-of-File or read error occurred on COSPAR.DAT file (file may not exist or path to this file may not be set appropriately).

Remedy:

Correct error condition (i.e., copy or restore file to right location). Rerun program.

---

#### Code Producing the Message:

```
80 If (lat .ne. -100+10*i)Stop ' Error reading HEIGHTS.DAT!' SETU150
```

#### Purpose:

To indicate a latitude read from HEIGHTS.DAT file was an unexpected value (file is missing, corrupted, or sized wrong based on parameters nlat and nlon).

#### Remedy:

Correct problem with HEIGHTS.DAT file. Rerun program.

---

#### Code Producing the Message:

```
Write(iu0,91) SETU157
91 Format(' Input error in month, day or year.') SETU158
```

#### Purpose:

To indicate an illegal value of month, day, or year input via the NAMELIST INPUT file.

#### Remedy:

Correct erroneous value(s). Rerun program.

---

#### Code Producing the Message:

```
Write(iu0,92) SETU170
92 Format(' Input error in hour, minute or seconds.') SETU171
```

#### Purpose:

To indicate an illegal value of hour, minute, or second input via the NAMELIST INPUT file.

#### Remedy:

Correct erroneous value(s). Rerun program.

---

Code Producing the Message:

```
260 Write(iu0,270)
270 format(' Unable to open Trajectory Data file!')
```

SETU191  
SETU192

Purpose:

To indicate an error occurred in attempt to open trajectory input data file TRAJDATA (file may not exist or may have wrong path set to its location).

Remedy:

Correct problem with TRAJDATA file. Rerun program.

-----

Code Producing the Message:

```
      If (als0 .gt. 0.)Write(iu0,*)' Ls outside range. ',
&      ' No dust storm assumed.'
```

SETU216  
SETU217

Purpose:

To indicate user attempted to simulate a dust storm for a value of areocentric longitude of the Sun (Ls) outside range 180 to 320. Message reminds user that dust storms cannot be simulated for Ls values outside this range and that no dust storm is being simulated during the run.

Remedy:

None necessarily required. If a dust storm case is desired, select a different Ls (180 < Ls < 320). Rerun program.

-----

Code Producing the Message:

```
      Write(iu0,*)' Intensity must be between 0 and 3'
```

SETU222

Purpose:

To indicate a dust storm intensity < 0.0 or > 3.0 was entered.

Remedy:

Input a dust storm intensity between 0.0 and 3.0 . Rerun program.

---

Code Producing the Message:

```
Write(iu0,*)' F10.7 must be between 50 and 450' SETU233
```

Purpose:

To indicate an F10.7 solar flux <50 or >450 was entered.

Remedy:

Input an F10.7 value between 50 and 450. Rerun program.

---

Code Producing the Message:

```
Write(iu0,*)' Std. deviations must be between -3 and +3' SETU237
```

Purpose:

To indicate a standard deviation in the Stewart thermosphere model <-3 or >+3 was entered (nominal value is 0.0).

Remedy:

Input a standard deviation value between -3 and +3. Rerun program.

---

Code Producing the Message:

```
291 Write(iu0,291) SETU241
Format(' Error in perturbation model number.') SETU242
```

Purpose:

To indicate a value of the perturbation model code less than 1 or greater than 3 was input via NAMELIST INPUT file.



Remedy:

Input a legal model number less than 1 or greater than 3. Rerun program.

Code Producing the Message:

```
Write(iu0,292) SETU247
292 Format(' Error in starting random number.') SETU248
```

Purpose:

To indicate a random number seed value of less than 1 or greater than 29999 was input via NAMELIST INPUT file.

Remedy:

Input a random number seed value greater than 0 and less than 30000. Rerun program.

Code Producing the Message:

```
Write(iu0,381) SETU295
381 Format(' x-code or y-code input error.') SETU296
```

Purpose:

To indicate a value of x-code outside the range 1 to 8, or y-code outside range 0 to 8 was input via NAMELIST INPUT file.

Remedy:

Select x-code and y-code values for plotable output, according to the following codes:

& ' Code	Parameter'/	
& ' 1	Height (above reference ellipsoid, km)'/	SETU283
& ' 2	Height (above local terrain, km)'/	SETU284
& ' 3	Latitude (deg.)'/	SETU285
& ' 4	West Longitude (deg.)'/	SETU286
& ' 5	Time from start (Earth seconds)'/	SETU287
& ' 6	Time from start (Martian Sols)'/	SETU288
& ' 7	Areocentric Longitude of Sun, Ls (deg.)'/	SETU289
& ' 8	Hour Angle for Local Time (Mars hours * 15)'/	SETU290
& ' Use y-code = 0 for plotable output vs x-code variable only'		SETU291
		SETU292
		SETU293

Rerun program.

---

Code Producing the Message:

```
      Write(iu0,382)                                SETU307
382   Format(' Error in first latitude or longitude.') SETU308
```

Purpose:

To indicate a starting latitude absolute value greater than 90, or a starting longitude less than 0 or greater than 360, was input via NAMELIST input file.

Remedy:

Input a legal value of starting latitude and longitude. Rerun program.

---

Code Producing the Message:

```
9998 Stop ' Error termination! Check the LIST file for messages.' SETU324
```

Purpose:

To indicate termination, i.e., a fatal error condition occurred. Normally error conditions are described by message preceding this on screen output. For some options and error conditions, additional error information may appear in LIST output file.

Remedy:

Correct the error(s) noted. Rerun program.

---

## 5.4 Subroutines in the File MARSSUBS

The subroutines in the MARSSUBS file produce diagnostic messages when certain error conditions occur. As an option, various diagnostic outputs are triggered by the user from within the Stewart thermosphere model, by setting FLAG (an integer) to a non-zero.

---

Code Producing the Message:

```
IF (IFault .EQ. 1)STOP ' PPND ERROR'                                DSTP 61
```

Purpose:

To indicate a fatal error occurred in random number routine PPND. This is abnormal and may indicate a system-level problem.

Remedy:

Rerun the program with a different random number seed (NR1). If problem persists, run system level diagnostic tests to see if RANDOM and PPND perform properly.

---

Code Producing the Message:

```
9998 Stop ' Error termination reading data file!'                    DSTP353
```

Purpose:

To indicate an error occurred while reading trajectory file TRAJDATA.

Remedy:

Correct data in TRAJDATA file. Rerun program.

---

Code Producing the Message:

```
C      if (FLAG .GT. 0)Write(iu0,170)LSUN,DFAO,DZ                    DZDS 23
C 170 FORMAT(' FROM PROC. DZDUST-- LSUN,DFAO,DZ = ',3F8.2)          DZDS 24
```

### Purpose:

This code is currently "commented out" (inactivated). If comment characters are removed from column 1 and if FLAG is set to a non-zero value and passed as an argument into subroutine DZDUST, then this optional diagnostic output is produced.

### Remedy:

After tests are completed and diagnostic output is not desired, set FLAG to 0 (in Stewart2 subroutine, line STW2 20).

### Code Producing the Message:

```
-----  
      if(FLAG.gt.0)Write(iu0,*)' RREF, RAU, GZ = ',RREF,RAU,GZ           STW2 32  
      if(FLAG.gt.0)Write(iu0,*)' ZF,CHGT,ZZF = ',ZF,CHGT,ZZF           STW2 44  
  
      Write(iu0,*)' RAU,FBARR,RREF,DR,DUST = '                          STW2 49  
      Write(iu0,150)RAU,FBARR,RREF,DR,DUST                             STW2 50  
150    FORMAT(F6.2,F7.2,F8.2,2F6.2,F8.2)                               STW2 51  
      Write(iu0,*)' '                                                  STW2 52  
      Write(iu0,*)'FROM PROC. DRAG-- ZF,RF,TINF,TF = '                 STW2 53  
      Write(iu0,160)ZF,RF,TINF,TF                                       STW2 54  
160    FORMAT(F7.2,F8.2,3F7.2)                                           STW2 55
```

### Purpose:

To produce this optional diagnostic output, set value of FLAG to a non-zero value.

### Remedy:

After tests are completed and diagnostic output is not desired, set FLAG to 0 (in Stewart2 subroutine, line STW2 20).

### Code Producing the Message:

```
-----  
      if (FLAG .GT. 0) then                                           THRM135  
        Write(iu0,220)ZZF,TZ,MOLWTG,TOTALPRZ,TOTALNDZ, (NDZ(K),K=0,3), THRM136  
      &    TOTALMDZ, (NDZ(K),K=4,8)                                     THRM137  
220    FORMAT(2F6.1,F5.1,6E10.3/17X,6E10.3)                           THRM138
```

**Purpose:**

To produce this optional diagnostic output, set the value of FLAG to a non-zero value and pass as an argument into subroutine THERMOS.

**Remedy:**

After tests are completed and diagnostic output is not desired, set FLAG to 0 (in Stewart2 subroutine, line STW2 20).

-----



## **6. FUTURE PLANS**

The NASA Marshall Space Flight Center (MSFC) and NASA Jet Propulsion Laboratory (JPL) are working a joint program of future upgrades and applications development for Mars-GRAM. The following is a brief outline of the development features under consideration.

### **6.1 Improved Mars Thermosphere Model**

The Stewart model thermosphere that serves as the basis for the upper altitudes in Mars-GRAM was designed to give global average values of density and other variables as a function of height and time. This means that latitude-longitude variations of thermospheric density, temperature, and pressure are unrealistic in Mars-GRAM. Since the wind components are based on extremely small horizontal pressure gradients (through the areostrophic or thermal wind relation), the winds estimated by Mars-GRAM in the thermosphere region are unrealistically small.

To improve the Mars-GRAM thermospheric values, output data from the Bougher et al. (1988) Mars Thermospheric Global Circulation Model (MTGCM) will be used to derive appropriate modifier factors for latitude and time-of-day (longitude), for application to the Stewart model values. Comparisons with MTGCM results may also improve the Mars-GRAM (Stewart) model dependence on the effects of solar activity (10.7 cm solar flux). With comparison of wind output from MTGCM, the wind model in Mars-GRAM, including the viscous modification model, also has potential for improvement.

### **6.2 Climatic Changes Since the Mariner-Viking (1970's) Time Period**

Because Mars-GRAM was developed from parameterizations to atmospheric data observed by the Mariner and Viking missions, the model is representative of the Mars atmosphere during the 1970's. Recent observations by Clancy et al. (1990) indicate, in response to atmospheric cooling as the dusty atmosphere has cleared in the last two decades, that current Mars temperature profiles are distinctly cooler than those observed in the Viking era. Comparisons of Mars-GRAM mid-latitude average temperature profiles with recent data from Clancy (provided by Rich Zurek, private communication), indicate about 20 K cooling at the 40-50 km height range, about 15 K at 20-30 km, but little change at 5-10 km. This temperature change could have significant effects on atmospheric density at high altitudes and, as Clancy et al. (1990) pointed out, is of considerable importance in planning for Mars missions that involve aerobraking.

Consider Mars-GRAM profiles of temperature, density and pressure to be  $T_0(z)$ ,  $\rho_0(z)$ , and  $p_0(z)$ , respectively, with the perfect gas law and hydrostatic relations applicable, namely,

$$p_0 = \rho_0 R T_0 \quad , \quad (23)$$

and

$$dp_0 / dz = - \rho_0 g = - p_0(z) / H(z) \quad . \quad (24)$$

Consider also that climatic changes up to the present time have induced new profiles of temperature, density and pressure,  $T_1(z)$ ,  $\rho_1(z)$  and  $p_1(z)$ . Application of equations (23) and (24) to both the original and the new atmospheric states yields the relation for density:

$$\delta \rho / \rho_0 = (\rho_1 - \rho_0) / \rho_0 = (T_0 / T_1) \exp \left( \int_0^z [(T_1 - T_0) / (T_0 H)] dz' \right) - 1 \quad . \quad (25)$$

Consider the simple example in which temperature has uniformly decreased by 5% between the surface and 100 km, i.e.,  $\delta T / T_0 = (T_1 - T_0) / T_0 \approx -0.05$  at all altitudes. Since the scale height,  $H$ , is about 10 km, the integral term in equation (25) would have a value of about -0.5 and the density change at 100 km altitude from equation (25) would be  $\delta \rho / \rho_0 = -36\%$ . In more general cases, the exact details of the density effect at altitude would, of course, depend on the profile of the temperature changes  $(T_1 - T_0)$  and the profile of the scale height values  $H(z)$ .

Another Mars-GRAM enhancement under consideration by MSFC and JPL is to use new atmospheric temperature profiles from the Clancy data (and/or or from prior missions, after the first new Mars mission) to derive a climate-shift option (i.e. to estimate current conditions with the climatic shift option on, or to estimate Viking era conditions with the new climate shift option off).

## **Mars-GRAM as an Operational Tool for Aerobraking**

MSFC and JPL are also interested in developing operational tools, based on Mars-GRAM, to use during the aerobraking phase of future Mars missions. Two potential approaches are to:



(1) Use Mars-GRAM densities evaluated near the periapsis position and time to compare with densities derived from the "real-time" orbit/trajectory analysis. Keep a time-series history of a "figure of merit" to monitor the trends of necessary adjustments to convert Mars-GRAM derived densities to actual densities for the aerobraking period. The figure of merit may be simply a ratio of Mars-GRAM value to the real time value or, perhaps, the value of the standard deviation (parameter STD<sub>L</sub> in the Stewart thermosphere model) required to get Mars-GRAM output to agree with real-time derived density. Once the observed trend in the figure of merit is established, use, in conjunction with Mars-GRAM calculations, to make short-term forecasts of the atmospheric density to be encountered over the next several passes through periapsis.

(2) Use other "real-time" measurements of temperature profiles (e.g., Clancy-type ground-based microwave observations or temperature profiler data from sensors onboard the Mars orbiter) to derive estimates of necessary corrections to be applied to Mars-GRAM output. In this mode, estimates of density deviations from Mars-GRAM are computed via equation (25), using estimates of observed temperature profile deviations from Mars-GRAM profiles.



## 7. BIBLIOGRAPHY

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## **APPENDIX A**

### **DESCRIPTION OF THE MARS-GRAM PROGRAM AND SUBROUTINES**

This Appendix gives descriptions of the interactive form (Mars-GRAM) main program, the batch form (MARSGRMB) main program, the subroutine SETUP (used only by the batch form), and each of the functions and subroutines in the file MARSSUBS (in alphabetical order by the line number code for the MARSSUBS routines). References to functions, subroutines, and variables used appear as either all capital letters or as upper and lower case. The FORTRAN compiler is assumed to be case-insensitive.

Each description gives: (1) function or subroutine name, (2) four-character line number code, (3) brief description of purpose of subroutine, (4) subroutine(s) that call function or subroutine, (5) common blocks used, and (6) list and descriptions of input variables, output variables, and local variables (those not passed through common blocks). For a list of variables in common blocks, see Table 2-3.

A technical discussion of methods used by each function or subroutine is also given. Reference is made to the actual line of program code, including line numbers, for easy cross-reference to the program code.

## 1. The Mars-GRAM Main Program (Interactive Form)

**Main Program:** Mars-GRAM (version 3.34)

**Code:** MARS

**Description:** Interactive form of the Mars-GRAM program.

**Called By:** N/A

**Common Blocks Used (See Table 2-3 for a list of variables in common blocks):**

COSPARNH, DATACOM, FILENAME, RANDCOM, TERHGT, THERM, WAVEDAT

**Input Variables (Read from interactive input):**

Name	Type	Description
ALSO	REAL*4	time (Ls value) for beginning of dust storm
DC	REAL*4	COSPAR density array
DELHGT	REAL*4	height increment (km)
DELLAT	REAL*4	northward latitude increment (degrees)
DELLON	REAL*4	westward longitude increment (degrees)
DELTIME	REAL*4	time increment (seconds)
DUSTLAT	REAL*4	latitude of local-scale dust storm
DUSTLON	REAL*4	longitude of local-scale dust storm
F107	REAL*4	10.7 cm solar flux at Earth position (1AU)
FHGT	REAL*4	first height (km)
FLAT	REAL*4	first latitude (degrees)
FLON	REAL*4	first longitude (degrees West)
IHR	INTEGER*4	hour of day (UTC or GMT)
IMIN	INTEGER*4	minute of hour
INTENS	REAL*4	intensity level for dust storm (0.0 to 3.0)
LAT	INTEGER*4	latitude for reading HEIGHTS.DAT input
LOGSCALE	INTEGER*4	output units for pressure and density (0=MKS, 1 = log-base-10 MKS, 2=%deviation from COSPAR)
LSTFL	CHAR*12	Name of LIST file
MDAY	INTEGER*4	day of month
MODPERT	INTEGER*4	perturbation model (1=random, 2=wave, 3=both)
MONTH	INTEGER*4	month of year
MYEAR	INTEGER*4	year (4 digit; can be 2-digit if 1970 to 2069)
NPOS	INTEGER*4	maximum number of automatically-generated positions
NR1	INTEGER*4	random number seed (1-30,000)
NVARX	INTEGER*4	x-coordinate plot variable (See MARS262-MARS274)
NVARY	INTEGER*4	y-coordinate plot variable (See MARS262-MARS274)
OUTFL	CHAR*12	Name of OUTPUT file
PC	REAL*4	COSPAR pressure array
RADMAX	REAL*4	maximum radius of dust storm (km; global if radmax=0 or radmax>10,000)
SEC	REAL*4	second of minute
STDL	REAL*4	number of standard deviations for thermospheric variation (-3.0 to +3.0)
TC	REAL*4	COSPAR temperature array
TH	REAL*4	terrain height array, read from HEIGHTS.DAT
ZC	REAL*4	COSPAR height array

**Output Variables (Includes echo out of some input variables):**

Name	Type	Description
-----	-----	-----
ALS	REAL*4	(Ls) areocentric longitude of sun
ALSO	REAL*4	time (Ls value) for beginning of dust storm
DATE	REAL*8	Julian date
DUSTLAT	REAL*4	latitude of local-scale dust storm
DUSTLON	REAL*4	longitude of local-scale dust storm
F107	REAL*4	10.7 cm solar flux at Earth position (1AU); program also writes out value at Mars position
IHR	INTEGER*4	hour of day (UTC or GMT)
IMIN	INTEGER*4	minute of hour
INTENS	REAL*4	intensity level for dust storm
MDAY	INTEGER*4	day of month
MODPERT	INTEGER*4	perturbation model (1=random, 2=wave, 3=both)
MONTH	INTEGER*4	month of year
MYEAR	INTEGER*4	year (4 digit; can be 2-digit if 1970 to 2069)
NPOS	INTEGER*4	maximum number of automatically-generated positions
NR1	INTEGER*4	random number seed
RADMAX	REAL*4	maximum radius of dust storm
SEC	REAL*4	second of minute
STDL	REAL*4	number of standard deviations for thermospheric variation
THGT	REAL*4	local elevation of surface (km)

**Local Variables (not passed through commons):**

Name	Type	Description
-----	-----	-----
ALS	REAL*4	(Ls) areocentric longitude of the sun
CHGT	REAL*4	current height
CLAT	REAL*4	current latitude
CLON	REAL*4	current longitude
CSEC	REAL*4	current time from start (seconds)
DATE	REAL*8	Julian date
DATE0	REAL*8	initial Julian data
DELHGT	REAL*4	height increment
DELLAT	REAL*4	latitude increment
DELLON	REAL*4	longitude increment
DELTIME	REAL*4	time increment
DENS	REAL*4	atmospheric density
DENSHI	REAL*4	high (approx. + 1 sigma) density
DENSLO	REAL*4	low (approx. - 1 sigma) density
DENSP	REAL*4	perturbation in density (% of mean)
EOF	INTEGER*4	End-of-file flag for trajectory file
EWIND	REAL*4	eastward vector wind component (m/s)
FHGT	REAL*4	first height (km)
FILES	CHAR*12	array of file names (see list of values elsewhere)
FLAT	REAL*4	first latitude
FLON	REAL*4	first longitude
GZERO	REAL*4	gravity acceleration at z=0
I	INTEGER*4	index variable
IDAY	INTEGER*4	day-of-year for beginning of each month
IERR	INTEGER*4	file open error flag array (equivalent to IERR1-IERR17)
IERR1	INTEGER*4	file open error flag
IERR10	INTEGER*4	file open error flag
IERR11	INTEGER*4	file open error flag
IERR12	INTEGER*4	file open error flag
IERR13	INTEGER*4	file open error flag
IERR14	INTEGER*4	file open error flag

IERR15	INTEGER*4	file open error flag
IERR16	INTEGER*4	file open error flag
IERR17	INTEGER*4	file open error flag
IERR2	INTEGER*4	file open error flag
IERR3	INTEGER*4	file open error flag
IERR4	INTEGER*4	file open error flag
IERR5	INTEGER*4	file open error flag
IERR6	INTEGER*4	file open error flag
IERR7	INTEGER*4	file open error flag
IERR8	INTEGER*4	file open error flag
IERR9	INTEGER*4	file open error flag
IHR	INTEGER*4	hour of day
IMIN	INTEGER*4	minute of hour
J	INTEGER*4	index value
L	INTEGER*4	index value
LAT	INTEGER*4	latitude for reading terrain heights
MARSAU	REAL*4	orbital position of Mars (in AU)
MAXNUM	INTEGER*4	maximum number of positions to compute
MDAY	INTEGER*4	day of month
MONTH	INTEGER*4	month of year
MYEAR	INTEGER*4	year
NDAY	INTEGER*4	day of year
NLAT	INTEGER*4	number of latitudes in terrain height array
NLON	INTEGER*4	number of longitudes in terrain height array
NR1	INTEGER*4	random number seed
NSWIND	REAL*4	northward vector wind component
PRES	REAL*4	atmospheric pressure
RHO	REAL*4	random number for sequence of perturbations
SEC	REAL*4	seconds of minute
SUNLAT	REAL*4	latitude of sub-solar position on surface
SUNLON	REAL*4	longitude of sub-solar position on surface
TEMP	REAL*4	atmospheric temperature (K)
THGT	REAL*4	height of terrain surface above reference ellipsoid
XYEAR	REAL*8	intermediate year for Julian day calculation

### Methodology:

The program prompts the user for values of the necessary input. Depending on the options selected, some input parameters assume default values and it is not necessary to input a value. Several input variables are also echoed back as output variable on the LIST file. All subroutines required by Mars-GRAM interactive form are contained in the marssubs file.

Mars-GRAM opens all input and output files, interactively reads the necessary input values and steps through the output positions, generating and writing the output. If the trajectory option is selected (NPOS=0), positions are read from the TRAJDATA file, until and end-of-file is encountered. If an automatically-generated profile of positions is used (NPOS>0), output continues until the maximum allowed number of output positions (MAXNUM=NPOS-1) has been exceeded.

If the time is within the period for dust storm formation ( $180 < L_s < 320$ ,  $L_s$  = areocentric longitude of sun), then a local-scale or a global-scale dust storm can be simulated. Position and or size of the dust storm are controlled by input values of DUSTLAT, DUSTLON, RADMAX and INTENS.



## 2. The Mars-GRAM Main Program (Batch Form)

**Main Program:** Marsgrmb (version 3.34)

**Code:** MARB

**Description:** Batch form of the Mars-GRAM program.

**Called By:** N/A

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

None

### Input Variables:

There are no input variables directly to Marsgrmb. Input data are read, in NAMELIST form, by the subroutine SETUP. An example of the NAMELIST input is as follows:

```
$INPUT
LSTFL   = 'LIST',    ! List file name (CON for console listing)      MARB 18
OUTFL   = 'OUTPUT', ! Output file name                               MARB 19
MONTH   = 7,         ! month of year                                           MARB 20
MDAY    = 20,        ! day of month                                           MARB 21
MYEAR   = 76,        ! year (4-digit; 1970-2069 can be 2-digit)      MARB 22
NPOS    = 21,        ! max # positions to evaluate (0 = read data    MARB 23
                                from TRAJDATA file)      MARB 24
IHR     = 12,        ! GMT hour of day                                           MARB 25
IMIN    = 30,        ! minute of hour                                           MARB 26
SEC     = 0.0,       ! second of minute (for initial position)      MARB 27
ALSO    = 0.0,       ! starting Ls value (degrees) for dust storm    MARB 28
                                (0 = none)      MARB 29
INTENS  = 0.0,       ! dust storm intensity (0.0 - 3.0)              MARB 30
RADMAX  = 0.0,       ! max. radius (km) of dust storm (0 or        MARB 31
                                >10000 = global)      MARB 32
DUSTLAT = 0.0,       ! latitude (deg) for center of dust storm      MARB 33
DUSTLON = 0.0,       ! West longitude (deg) of center of dust storm MARB 34
F107    = 185.0,     ! 10.7 cm solar flux (10**-22 W/cm**2 at 1 AU) MARB 35
STDLL   = 0.0,       ! std. dev. for thermosphere variation (-3.0  MARB 36
                                to +3.0)      MARB 37
MODPERT = 3,         ! perturbation model; 1=random, 2=wave, 3=both MARB 38
NR1     = 1001,      ! starting random number (0 < NR1 < 30000)      MARB 39
NVARX   = 2,         ! x-code for plotable output (1=hgt above ref. MARB 40
                                ellipse)      MARB 41
NVARY   = 0,         ! y-code for 2-D plotable output (0 for 1-D    MARB 42
                                plots)      MARB 43
LOGSCALE = 0,        ! 1 for log-base-10 scale plots, 0 for linear  MARB 44
                                scale, 2 for % deviation from COSPAR MARB 45
FLAT    = 22.0,      ! initial latitude (N positive), degrees       MARB 46
FLON    = 48.0,      ! initial longitude (West positive), degrees   MARB 47
FHGT    = -0.5,      ! initial height (km), above ref. ellipse      MARB 48
DEHGT   = 10.0,      ! height increment (km) between steps          MARB 49
DELLAT  = 0.0,       ! latitude increment (deg) between steps       MARB 50
DELLON  = 0.0,       ! West longitude increment (deg) between steps MARB 51
DELTIME = 0.0,       ! time increment (sec) between steps           MARB 52
$END
```

### Output Variables:

There are no output variables that are produced directly by Marsgrmb. Standard LIST and OUTPUT files (as well as the output files for graphics

input, units 21-34) may be produced by subroutine DATASTEP. The Marsgrmb batch form is designed so that the output variables from DATASTEP may easily be output by the user (or passed to other user subroutines), in whatever format is desired. Output variables from DATASTEP are:

TEMP = temperature (K)	MARB 98
PRES = pressure (N/m**2)	MARB 99
DENSLO = nominal low density (kg/m**3), approx. -1 sigma	MARB100
DENS = mean density (kg/m**3)	MARB101
DENSHI = nominal high density (kg/m**3), approx. +1 sigma	MARB102
DENSP = density perturbation about mean (% of mean)	MARB103
EWIND = eastward wind component (m/s)	MARB104
NSWIND = northward wind component (m/s)	MARB105

If none of the LIST file or OUTPUT file or graphics file output is desired, this is accomplished by setting file unit parameter iup = 0, in line BLKD 16.

#### Local Variables (not passed through commons):

Name	Type	Description
CHGT	REAL*4	current height
CLAT	REAL*4	current latitude
CLON	REAL*4	current longitude
CSEC	REAL*4	current time from start (seconds)
DATE0	REAL*8	initial Julian date
DELHGT	REAL*4	height increment
DELLAT	REAL*4	latitude increment
DELLON	REAL*4	longitude increment
DELTIME	REAL*4	time increment
DENS	REAL*4	atmospheric density
DENSHI	REAL*4	high (approx. + 1 sigma) density
DENSLO	REAL*4	low (approx - 1 sigma) density
DENSP	REAL*4	perturbation in density (% of mean)
EOF	INTEGER*4	End-of-file flag for trajectory file
EWIND	REAL*4	eastward vector wind component
I	INTEGER*4	index variable
MAXNUM	INTEGER*4	maximum number of positions to compute
NSWIND	REAL*4	northward vector wind component
PRES	REAL*4	atmospheric pressure
RHO	REAL*4	random number for sequence of perturbations
TEMP	REAL*4	atmospheric temperature (K)

#### Methodology:

Stripped of all of the embedded comment statements, the batch form Marsgrmb consists of only the following lines of code. All variables are initialized through the SETUP subroutine and parameters are evaluated at successive locations (either trajectory or automatic profile mode) with the DATASTEP subroutine. Any desired output (or transfer to other subroutines) can be done within the loop that calls DATASTEP.

```
DOUBLE PRECISION DATE0
Real NSWIND
Integer EOF
Call Setup(CHGT,CLAT,CLON,CSEC,DATE0,RHO,DELHGT,DELLAT,DELLON,
& DELTIME,MAXNUM)
DO 900 I = 0,MAXNUM
  Call Datastep(I,CHGT,CLAT,CLON,CSEC,DATE0,RHO,EOF,DELHGT,
&  DELLAT,DELLON,DELTIME,TEMP,PRES,DENSLO,DENS,DENSHI,DENSP,
&  EWIND,NSWIND)
```

```
      If (EOF .eq. 1)Goto 999
900 Continue
999 STOP ' Normal Termination'
END
```

### 3. Description of the SETUP Subroutine (for the Batch Form)

**Subroutine:** SETUP

**Code:** SETU

**Description:** Opens files and reads input data for the Marsgrmb batch form program.

**Called By:** Marsgrmb (main)

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

COSPARNH, DATACOM, FILENAME, RANDCOM, TERHGT, THERM

**Input Variables:**

Input data are read, in NAMELIST form, by the subroutine SETUP. An example of the NAMELIST input is as follows:

\$INPUT		MARB 18
LSTFL	= 'LIST', ! List file name (CON for console listing)	MARB 19
OUTFL	= 'OUTPUT', ! Output file name	MARB 20
MONTH	= 7, ! month of year	MARB 21
MDAY	= 20, ! day of month	MARB 22
MYEAR	= 76, ! year (4-digit; 1970-2069 can be 2-digit)	MARB 23
NPOS	= 11, ! max # positions to evaluate (0 = read data	MARB 24
	! from TRAJDATA file)	MARB 25
IHR	= 12, ! GMT hour of day	MARB 26
IMIN	= 30, ! minute of hour	MARB 27
SEC	= 0.0, ! second of minute (for initial position)	MARB 28
ALS0	= 0.0, ! starting Ls value (degrees) for dust storm	MARB 29
	! (0 = none)	MARB 30
INTENS	= 0.0, ! dust storm intensity (0.0 - 3.0)	MARB 31
RADMAX	= 0.0, ! max. radius (km) of dust storm (0 or	MARB 32
	! >10000 = global)	MARB 33
DUSTLAT	= 0.0, ! latitude (deg) for center of dust storm	MARB 34
DUSTLON	= 0.0, ! West longitude (deg) of center of dust storm	MARB 35
F107	= 185.0, ! 10.7 cm solar flux (10**-22 W/cm**2 at 1 AU)	MARB 36
STD L	= 0.0, ! std. dev. for thermosphere variation (-3.0	MARB 37
	! to +3.0)	MARB 38
MODPERT	= 3, ! perturbation model; 1=random, 2=wave, 3=both	MARB 39
NR1	= 1001, ! starting random number (0 < NR1 < 30000)	MARB 40
NVARX	= 1, ! x-code for plotable output (1=hgt above ref.	MARB 41
	! ellipse)	MARB 42
NVARY	= 0, ! y-code for 2-D plotable output (0 for 1-D	MARB 43
	! plots)	MARB 44
LOGSCALE	= 0, ! 1 for log-base-10 scale plots, 0 for linear	MARB 45
	! scale, 2 for % deviation from COSPAR	MARB 46
FLAT	= 22.0, ! initial latitude (N positive), degrees	MARB 47
FLON	= 48.0, ! initial longitude (West positive), degrees	MARB 48
FHGT	= -0.5, ! initial height (km), above ref. ellipse	MARB 49
DELHGT	= 10.0, ! height increment (km) between steps	MARB 50
DELLAT	= 0.0, ! latitude increment (deg) between steps	MARB 51
DELLON	= 0.0, ! West longitude increment (deg) between steps	MARB 52
DELTIME	= 0.0, ! time increment (sec) between steps	MARB 53
\$END		

**Output Variables (not passed through commons):**

Name	Type	Description
CHGT	REAL*4	current height
CLAT	REAL*4	current latitude
CLON	REAL*4	current longitude
CSEC	REAL*4	current time (seconds)
DATE0	REAL*4	initial Julian date
DHGT	REAL*4	height increment
DLAT	REAL*4	latitude increment
DLOX	REAL*4	longitude increment
DTIME	REAL*4	time increment (seconds)
MAXNUM	INTEGER*4	maximum number of positions to compute
RHO	REAL*4	random number for sequence of perturbations

**Local Variables (not passed through commons):**

Name	Type	Description
ALS	REAL*4	areocentric longitude of the sun (Ls)
DATE	REAL*8	Julian date
DELHGT	REAL*4	height increment
DELLAT	REAL*4	latitude increment
DELLON	REAL*4	longitude increment
DELTIME	REAL*4	time increment
FILES	CHAR*12	file name array (see Table with list of files)
GZERO	REAL*4	acceleration of gravity at z = 0
I	INTEGER*4	index variable
IDAY	INTEGER*4	day-of-year for beginning of each month
IERR	INTEGER*4	file open error flag array (equivalent to IERR1-IERR17)
IERR1	INTEGER*4	file open error flag
IERR10	INTEGER*4	file open error flag
IERR11	INTEGER*4	file open error flag
IERR12	INTEGER*4	file open error flag
IERR13	INTEGER*4	file open error flag
IERR14	INTEGER*4	file open error flag
IERR15	INTEGER*4	file open error flag
IERR16	INTEGER*4	file open error flag
IERR17	INTEGER*4	file open error flag
IERR2	INTEGER*4	file open error flag
IERR3	INTEGER*4	file open error flag
IERR4	INTEGER*4	file open error flag
IERR5	INTEGER*4	file open error flag
IERR6	INTEGER*4	file open error flag
IERR7	INTEGER*4	file open error flag
IERR8	INTEGER*4	file open error flag
IERR9	INTEGER*4	file open error flag
J	INTEGER*4	index variable
L	INTEGER*4	index variable
LAT	INTEGER*4	latitude for reading terrain heights
MARSAU	REAL*4	orbital position of Mars (in AU)
NDAY	INTEGER*4	day of month
NLAT	INTEGER*4	number of latitudes in terrain height array
NLOX	INTEGER*4	number of longitudes in terrain height array
SUNLAT	REAL*4	latitude of sub-solar position on surface
SUNLOX	REAL*4	longitude of sub-solar position on surface
THGT	REAL*4	height of terrain surface above reference ellipsoid
XYEAR	REAL*8	intermediate year for Julian day calculation

**Methodology:**

Reads NAMELIST input values (see above), computes Julian day, open output files and passes data to the Marsgrmb main program through the common blocks.

#### 4. Description of the MARSSUBS.FOR Functions and Subroutines

**Function:** Alb

**Code:** ALBL

**Description:** Surface albedo as a function of areocentric longitude of the sun (Ls) and latitude.

**Called By:** Tsurface

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

None

**Input Variables (not passed through commons):**

Name	Type	Description
als . . .	REAL*4	areocentric longitude of sun (Ls), degrees
alat. . .	REAL*4	latitude, degrees

**Output Variables (not passed through commons):**

Name	Type	Description
Alb . . .	REAL*4	surface albedo

**Local Variables (not passed through commons):**

Name	Type	Description
al. . . .	REAL*4	intermediate variable for albedo calculation
alsc. . .	REAL*4	Ls phase for polar hood cloud
caprad. .	REAL*4	polar cap radius, degrees
cldrad. .	REAL*4	polar hood cloud radius, degrees
pi180 . .	REAL*4	factor for degrees to radians
radc. . .	REAL*4	radius amplitude for polar hood cloud

##### **Methodology:**

Computes albedo of non-polar surface as

$$al = 0.32 - 0.12 * \cos(\pi 180 * alat)$$
 ALBL 9

Computes radius for polar hood cloud from

$$cldrad = radc * (1. + \cos(\pi 180 * (als - alsc)))$$
 ALBL 22

where alsc = 280., radc = 20. for North polar hood cloud and alsc = 60. and radc = 27. for South polar hood cloud. If the latitude is poleward of the polar hood cloud radius, the surface albedo is increased by 15 %

$$\text{If } (abs(alat) \geq 90. - cldrad) al = 1.15 * al$$
 ALBL 24

The radius of the polar cap is computed from the polecap function

```
caprad = polecap(alat,als)
```

ALBL 26

If the latitude is poleward of the polar cap radius, the surface albedo is set to 0.6

```
If (abs(alat) .ge. 90. - caprad)al = 0.6
```

ALBL 28



**Function:** ampint

**Code:** AMPN

**Description:** Interpolate wave amplitudes, linearly on input variable

**Called By:** Wavepert

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

None

**Input Variables (not passed through commons):**

Name	Type	Description
amp1. . .	REAL*4	amplitude at 1st value of input variable (x1)
amp2. . .	REAL*4	amplitude at 2nd value of input variable (x2)
dx. . . .	REAL*4	relative difference in input [(x-x1)/(x2-x1)]

**Output Variables (not passed through commons):**

Name	Type	Description
ampint. .	REAL*4	interpolated value of wave amplitude

**Local Variables (not passed through commons):**

Name	Type	Description
None		

**Methodology:**

Interpolates linearly to position x, between amp1 (at x1) and amp2 (at x2) by the relation

$$\text{ampint} = \text{amp1} + (\text{amp2} - \text{amp1}) * \text{dx} \quad \text{AMPN} \quad 2$$

where  $\text{dx} = (x - x1)/(x2-x1)$ . The input variable x may be height or latitude.

**Subroutine:** ATMOS2

**Code:** ATM2

**Description:** Driver routine to call either the STEWART2 thermosphere model or the stratos, lower altitude model, depending on the current height

**Called By:** Datastep

**Common Blocks Used (See Table 2-3 for a list of variables in common blocks):**

THERM

**Input Variables (not passed through commons):**

Name	Type	Description
ALS. . . .	REAL*4	areocentric longitude of the sun (Ls), degrees
ALSO . . .	REAL*4	initial value of areocentric longitude of the sun
CHGT . . .	REAL*4	current height (km)
CLAT . . .	REAL*4	current latitude (degrees)
CLON . . .	REAL*4	current West longitude (degrees)
DUSTA. . .	REAL*4	dust storm magnitude (0-1) for daily amplitude
DUSTM. . .	REAL*4	dust storm magnitude (0-1) for average T and p
INTENS . .	REAL*4	dust storm intensity (0.0 - 3.0)
IU0. . . .	INTEGER*4	unit number for screen output messages
MARSAU . .	REAL*4	Mars orbital radius (AU)
SUNLAT . .	REAL*4	latitude of sub-solar position (degrees)
SUNLON . .	REAL*4	West longitude of sub-solar position (degrees)
Z0 . . . .	REAL*4	local terrain height rel. to ref. ellipsoid (km)

**Output Variables (not passed through commons):**

Name	Type	Description
BRUNTF . .	REAL*4	Brunt-Vaisala frequency
DENST. . .	REAL*4	atmospheric density ( $\text{kg/m}^3$ ) at output position
DENSURF. .	REAL*4	atmospheric density ( $\text{kg/m}^3$ ) at surface
H. . . . .	REAL*4	scale height (km) at output position
LWFCTR . .	REAL*4	lower deviation factor for density
PRES . . .	REAL*4	atmospheric pressure ( $\text{N/m}^2$ )
RSC. . . .	REAL*4	areocentric radius to output position (km)
TAVG . . .	REAL*4	daily average surface temperature (K)
TEMP . . .	REAL*4	temperature at output position (K)
TFACOR. .	REAL*4	density perturbation factor at base of thermosphere
TMAX . . .	REAL*4	daily maximum surface temperature (K)
TMIN . . .	REAL*4	daily minimum surface temperature (K)
UPFCTR . .	REAL*4	upper deviation factor for density
ZF . . . .	REAL*4	height of base of thermosphere (km)

**Local Variables (not passed through commons):**

Name	Type	Description
AMF . . . .	REAL*4	molecular weight at base of thermosphere
AMHI. . . .	REAL*4	molecular weight for high density
AMLO. . . .	REAL*4	molecular weight for low density
AMW . . . .	REAL*4	average molecular weight, surface to turbopause
BVF . . . .	REAL*4	Brunt-Vaisala frequency
BVF0 . . .	REAL*4	Brunt-Vaisala frequency at surface
DENSHI. . .	REAL*4	high (approx. +1 sigma) density
DENSLO. . .	REAL*4	low (approx. -1 sigma) density

DLON. . . .	REAL*4	longitude difference between sun and output position
DR. . . .	REAL*4	Correction to ZF for pressure variation
DUST. . . .	REAL*4	Correction to ZF for dust storm
ES. . . .	REAL*4	long-term standard deviations about nominal ZF
GAM. . . .	REAL*4	temperature lapse rates between significant heights
GAM0. . . .	REAL*4	mean lapse rates, for use in perturbation model
GOR. . . .	REAL*4	gravity divided by gas constant
GPH. . . .	REAL*4	areopotential heights at significant levels
GPHGT. . . .	REAL*4	areopotential height difference for interpolation
GZ. . . .	REAL*4	gravity at output position
GZERO. . . .	REAL*4	surface gravity
HHI. . . .	REAL*4	scale height for high density
HLO. . . .	REAL*4	scale height for low density
I. . . .	INTEGER*4	index variable
J. . . .	INTEGER*4	index variable
P. . . .	REAL*4	array of pressures at significant levels
PAVG. . . .	REAL*4	daily average surface pressure
PF. . . .	REAL*4	intermediate value in pressure calculation
PFAC. . . .	REAL*4	Seasonal relative pressure variation
PRESHI. . . .	REAL*4	pressure for high density
PRESLO. . . .	REAL*4	pressure for low density
PSURF. . . .	REAL*4	local position surface pressure
RBAR. . . .	REAL*4	gas constant for Martian atmosphere up to turbopause
RREF. . . .	REAL*4	reference radius to Cain 6.1 mb surface
RSTAR. . . .	REAL*4	Universal gas constant
SHGT. . . .	REAL*4	height for call to thermosphere model
SMA. . . .	REAL*4	semi-major axis of Mars orbit
T. . . .	REAL*4	array of temperatures at significant levels
TOBAR. . . .	REAL*4	average surface temperature without dust storm effect
TEMPHI. . . .	REAL*4	temperature for high density
TEMPLO. . . .	REAL*4	temperature for low density
TF. . . .	REAL*4	intermediate value in temperature calculation
TGRAD. . . .	REAL*4	temperature gradient used in Brunt-Vaisala calculation
TIME. . . .	REAL*4	local solar time
TO. . . .	REAL*4	factor used in correction to ZF for pressure variation
TSURF. . . .	REAL*4	average surface temperature with dust storm effect
Z. . . .	REAL*4	areographic heights at significant levels

### Methodology:

Evaluates surface temperature (K), by calling Tsurface (ATM2 56). Evaluates acceleration of gravity at altitude CHGT by calling RELIPS (ATM2 59). Gets mean temperature lapse rates, for use in perturbation model, by calling Gamma (ATM2 62). Evaluates temperatures at significant levels (0.,5.,15.,30.,50.,75. areopotential km) by calling Temps (ATM2 69). Evaluates surface pressure, N/m<sup>2</sup>, by calling Psurface (ATM2 71). Evaluates pressure at significant levels by calling Pressure (ATM2 74). Gets surface density from perfect gas law

```
densurf = psurf/(Rbar*Tsurf)
```

ATM2 76

Computes Brunt Vaisala frequency at surface

```
bvf0 = gzero*(tgrad + gzero/Cp(Tsurf))/Tsurf
if (bvfo .lt. 0.0)bvfo = 1.0E-5
bvfo = Sqrt(bvfo)
```

ATM2 79

ATM2 80

ATM2 81

If the current height is below -5 km, the surface conditions are returned and the subroutine is exited (ATM2 82 - ATM2 93). If the current height is below z(5) (areographic height for 75 km areopotential height), ATMOS2 uses the lapse rates from the significant levels to interpolate for temperature, pressure and density

```

TEMP = T(j) - gam(j+1)*gphgt
If (abs(gam(j+1)) .gt. 0.001)then
  PRES = p(j)*exp(gorR*alog(TEMP/T(j))/gam(j+1))
Else
  PRES = p(j)*exp(-gorR*gphgt/T(j))
Endif
DENST = PRES/(Rbar*TEMP)

```

ATM2101  
ATM2102  
ATM2103  
ATM2104  
ATM2105  
ATM2106  
ATM2107

and solves for the Brunt-Vaisala frequency and high and low density factors

```

bvf = gz*(tgrad + gz/Cp(TEMP))/TEMP
if (bvf .le. 0.0)bvf = 1.0E-5
Bruntf = Sqrt(bvf)
C... UPFCTR = density and temperature part of un-damped mountain
C    waves
UPFCTR = (bvf0*Bruntf/gz)*Sqrt(densurf/DENST)
LWFCTR = 0.0

```

ATM2112  
ATM2113  
ATM2114  
ATM2115  
ATM2116  
ATM2117  
ATM2118

If the current height is above  $z(5)$ , then conditions are evaluated at height ZF, the base of the thermosphere (ATM2143 and ATM2146). If the current height is above  $z(5)$  but below ZF, values are found by interpolation, using the Stratos subroutine (ATM2150 - ATM2163). If the current height is above the base of the thermosphere, values are computed from the STEWART2 thermosphere model (ATM2164 - ATM2172).

**Subroutine:** Block Data

**Code:** BLKD

**Description:** Loads data values into common blocks, for use by various subroutines in the program

**Called By:** N/A

**Common Blocks Used (See Table 2-3 for a list of variables in common blocks):**

DATAKOM, WAVEDAT

**Input Variables (not passed through commons):**

Name	Type	Description
-----	-----	-----
None		

**Output Variables (not passed through commons):**

Outputs the variables in the commons DATAKOM and WAVEDAT

**Local Variables (not passed through commons):**

Name	Type	Description
-----	-----	-----
None		

**Methodology:**

Uses data statements to fill the arrays and assign values to the variables in the commons DATAKOM and WAVEDAT. These commons are used by several subroutines (see Table 2-2).

**Subroutine:** cospar

**Code:** COSP

**Description:** Computes COSPAR northern hemisphere mean values of pressure, density and temperature as a function of height.

**Called By:** Datastep

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

cosparnh

**Input Variables (not passed through commons):**

Name	Type	Description
z . . . . .	REAL*4	height (km) at which to evaluate COSPAR data

Input arrays of COSPAR temperature (tc, K), pressure (pc, mb) and density (dc, g/m\*\*3) come from the common COSPARNH, from data in the COSPAR.DAT file.

**Output Variables (not passed through commons):**

Name	Type	Description
p . . . . .	REAL*4	COSPAR pressure (N/m <sup>2</sup> ) at height z
rho . . . . .	REAL*4	COSPAR density (kg/m <sup>3</sup> ) at height z
t . . . . .	REAL*4	COSPAR temperature (K) at height z

**Local Variables (not passed through commons):**

Name	Type	Description
aexp . . .	REAL*4	exponent for constant lapse rate interpolation
dz . . . .	REAL*4	relative height displacement for interpolation
H . . . . .	REAL*4	scale height for isothermal interpolation
iz . . . . .	INTEGER*4	height index for interpolation
R . . . . .	REAL*4	interpolated gas law constant
R1 . . . . .	REAL*4	gas constant at lower interpolation height
R2 . . . . .	REAL*4	gas constant at upper interpolation height

### Methodology:

Uses an array of COSPAR data values (loaded in from the COSPAR.DAT file). The height interval is 1 km from -5 to 130 km and 10 km from 130 to 360 km. Computed height index, iz, is for the COSPAR height value just below the desired height z (COSP 10 - COSP 14). Return zero values if the height is outside the range -5 to 360 km. (COSP 16 - COSP 21).

Uses linear interpolation on temperature

dz = (z - zc(iz))/(zc(iz+1) - zc(iz))	COSP 24
t = tc(iz) + (tc(iz+1) - tc(iz))*dz	COSP 25

Uses a constant lapse rate, power-law interpolation (unless the layer is isothermal)

```

aexp = Alog(pc(iz+1)/pc(iz))/Alog(tc(iz+1)/tc(iz))      COSP 28
p = 100.*pc(iz)*(t/tc(iz))**aexp                        COSP 29

```

Uses an exponential (constant scale height) interpolation if isothermal conditions prevail

```

H = (zc(iz+1) - zc(iz))/Alog(pc(iz)/pc(iz+1))          COSP 31
p = 100.*pc(iz)*exp(-(z-zc(iz))/H)                     COSP 32

```

Computes density by linearly interpolating on gas constant and applying the perfect gas law relation

```

R1 = pc(iz)/(dc(iz)*tc(iz))                             COSP 35
R2 = pc(iz+1)/(dc(iz+1)*tc(iz+1))                       COSP 36
R = R1 + (R2-R1)*dz                                     COSP 37
C density from perfect gas law (and convert units to kg/m**3) COSP 38
rho = 10.*p/(R*t)                                       COSP 39

```

**Function:** Cp

**Code:** CPOT

**Description:** Specific heat at constant pressure, for a CO2 atmosphere, as a function of temperature.

**Called By:** ATMOS2

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

None

**Input Variables** (not passed through commons):

Name	Type	Description
T . . . .	REAL*4	temperature (K)

**Output Variables** (not passed through commons):

Name	Type	Description
Cp. . . .	REAL*4	specific heat ( $\text{J kg}^{-1} \text{K}^{-1}$ )

**Local Variables** (not passed through commons):

Name	Type	Description
None		

**Methodology:**

Computes Cp(T) from formula

$$C_p = 639.5 + 0.123687 \cdot T + 0.00200225 \cdot T^2$$

CPOT 4



**Subroutine:** Dustfact

**Code:** DSTF

**Description:** Computes relative dust storm intensity factors dustM and dustA as a function of the time since start of the storm, (als - als0), measured in Ls angle (degrees), and as a function of the storm intensity, intens. dustM is for relative magnitude of effect on daily average temperature and pressure. dustA is for relative magnitude of effect on diurnal (and semi-diurnal) amplitudes for temperature and pressure.

**Called By:** Datastep

**Common Blocks Used (See Table 2-3 for a list of variables in common blocks):**

DATA COM

**Input Variables (not passed through commons):**

Name	Type	Description
ALS . . . .	REAL*4	Areocentric longitude of sun (Ls)
CLAT. . . .	REAL*4	current latitude
CLON. . . .	REAL*4	current longitude
HGT . . . .	REAL*4	current height

**Output Variables (not passed through commons):**

Name	Type	Description
DUSTA . . .	REAL*4	relative magnitude for dust storm effects on daily variation amplitudes for temperature and pressure
DUSTM . . .	REAL*4	relative magnitude for dust storm effects on daily average temperature and pressure

**Local Variables (not passed through commons):**

Name	Type	Description
DEW . . . .	REAL*4	east-west component of distance from dust storm center
DLS . . . .	REAL*4	Ls difference from starting Ls (Ls0) for dust storm
DNS . . . .	REAL*4	north-south distance component from dust storm center
HGTDUST . .	REAL*4	vertical size to top of dust storm
RAD . . . .	REAL*4	radial distance from dust storm center
RADDUST . .	REAL*4	full horizontal radius of dust storm size
SIZEFACT. .	REAL*4	shape factor to compute DUSTA and DUSTM at location

**Methodology:**

Computes Ls difference (dls, degrees) from Ls value at start of dust storm (Ls0), and returns zero dust storm effect if dls < 0 or dls > 48.

```
dls = als - als0
If (dls .le. 0.0 .or. dls .gt. 48.0)then
    dustM = 0.0
    dustA = 0.0
Return
Endif
```

DSTF 14  
DSTF 15  
DSTF 16  
DSTF 17  
DSTF 18  
DSTF 19

Computes an initial factor value dustM that increases linearly from 0 to 1 as dls increases from 0 to 6 degrees, decreases from 1 back to 0 as dls varies between 24 and 48 degrees, or dustM = 1 otherwise.

```

If (dls .le. 6.0)then                                DSTF 20
    dustM = dls/6.                                    DSTF 21
Else If (dls .ge. 24.)then                            DSTF 22
    dustM = 2. - dls/24.                              DSTF 23
Else                                                    DSTF 24
    dustM = 1.0                                        DSTF 25
Endif                                                  DSTF 26

```

Computes an initial factor value dustA that increases linearly from 0 to 1 as dls increases from 0 to 9, decreases from 1 back to 0 as dls varies between 18 and 48 degrees, or dustA = 1 otherwise.

```

If (dls .le. 9.0)then                                DSTF 27
    dustA = dls/9.0                                    DSTF 28
Else If (dls .ge. 18.)then                            DSTF 29
    dustA = (48. - dls)/30.                          DSTF 30
Else                                                    DSTF 31
    dustA = 1.0                                        DSTF 32
Endif                                                  DSTF 33

```

Computes the size factor, sizefact, based on the position from the center of the dust storm and the maximum horizontal and vertical size of the storm.

```

sizefact = 1.0                                        DSTF 34
If (radmax .ne. 0.0)Then                              DSTF 35
    sizefact = 0.0                                    DSTF 36
    dns = DTR*Rref*(CLAT - dustlat)                  DSTF 37
    dew = DTR*Rref*cos(DTR*CLAT)*(CLON - dustlon)     DSTF 38
    rad = Sqrt(dns**2 + dew**2)                       DSTF 39
    raddust = dustM*radmax                             DSTF 40
    hgt dust = dustM*dusthgt                          DSTF 41
    If (rad .lt. 2.0*raddust .and. HGT .lt. 2.0*hgt dust) DSTF 42
&    sizefact = 0.25*(1.0 + cos(90.*DTR*rad/raddust))* DSTF 43
&    (1.0 + cos(90.*DTR*HGT/hgt dust))                DSTF 44
Endif                                                  DSTF 45

```

Computes the final dust storm factor values dustM and dustA, including the effects of time from start of the storm, the size factor based on position within the storm, and the storm intensity (0-3).

```

dustM = sizefact*dustM*intens/3.                    DSTF 46
dustA = sizefact*dustA*intens/3.                    DSTF 47

```

**Subroutine:** Datastep

**Code:** DSTP

**Description:** Driver routine for calling the atmospheric models and evaluating the winds and the density perturbations.

**Called By:** MarsGRAM (Main), Marsgrmb (Main)

**Common Blocks Used (See Table 2-3 for a list of variables in common blocks):**

COSPARNH, DATACOM, FILENAME

**Input Variables (not passed through commons):**

Name	Type	Description
CHGT. . . .	REAL*4	current height
CLAT. . . .	REAL*4	current latitude
CLON. . . .	REAL*4	current West longitude
CSEC. . . .	REAL*4	current time
DATE0 . . .	REAL*4	Julian date for initial position
DELHGT. . .	REAL*4	height displacement between successive positions
DELLAT. . .	REAL*4	latitude displacement between successive positions
DELLON. . .	REAL*4	longitude displacement between successive positions
DELTIME . .	REAL*4	time displacement between successive positions
EOF . . . .	INTEGER*4	flag for end of file on trajectory input
I . . . . .	INTEGER*4	position counter index
RHO . . . .	REAL*4	previous density perturbation value for perturbation model

**Output Variables (not passed through commons):**

Name	Type	Description
DENS. . . .	REAL*4	average atmospheric density
DENSHI. . .	REAL*4	high density (approx. +1 sigma)
DENSLO. . .	REAL*4	low density (approx. -1 sigma)
DENSP . . .	REAL*4	density perturbation (% from mean value)
EWIND. . . .	REAL*4	Eastward wind component
NSWIND. . .	REAL*4	Northward wind component
PRES. . . .	REAL*4	atmospheric pressure
TEMP. . . .	REAL*4	atmospheric temperature

**Local Variables (not passed through commons):**

Name	Type	Description
ABSWLAT . .	REAL*4	absolute value of latitude, for wind calculations
ALOGDENS. .	REAL*4	log (base 10) density
ALS . . . .	REAL*4	areocentric longitude of the sun (Ls)
AMPL. . . .	REAL*4	diurnal amplitude in Zurek wave model
AMP2. . . .	REAL*4	semi-diurnal amplitude in Zurek wave model
AREAHGT . .	REAL*4	area-averaged terrain height
BRUNTF. . .	REAL*4	Brunt-Vaisala frequency
BVF . . . .	REAL*4	dummy argument in ATMOS2 for Brunt-Vaisala frequency
CD. . . . .	REAL*4	geostrophic drag coefficient
CHGTS . . .	REAL*4	height above local terrain
CLATM . . .	REAL*4	negative displaced latitude for wind calculations
CLATP . . .	REAL*4	positive displaced latitude for wind calculations

CLONM . . .	REAL*4	negative displaced longitude for wind calculations
CLONP . . .	REAL*4	positive displaced longitude for wind calculations
CORIOL . . .	REAL*4	Coriolis parameter for wind calculations
CORREL . . .	REAL*4	one-step correlation value for density perturbations
COSFAC . . .	REAL*4	cosine factor used in wind calculations
COSWLAT . . .	REAL*4	cosine of absolute value of latitude
DAMPING . . .	REAL*4	viscous damping factor in mountain wave perturbations
DATE . . .	REAL*8	current Julian date
DCOS . . .	REAL*4	COSPAR model atmospheric density
DELEW . . .	REAL*4	E-W displacement between previous and current position (DSTP 77); also E-W distance (= 5° longitude), for wind calculation (DSTP129)
DELNS . . .	REAL*4	N-S displacement between previous and current position (DSTP 76); also N-S distance (= 5° latitude), for wind calculation (DSTP120)
DELZ . . .	REAL*4	height displacement, previous to current position
DEN0 . . .	REAL*4	dummy surface density argument for ATMOS2 subroutine
DENOM . . .	REAL*4	denominator term in wind calculations
DENSURF . . .	REAL*4	atmospheric density at surface
DENSWA . . .	REAL*4	density wave perturbation amplitude, %
DEVAV . . .	REAL*4	deviation of average density from COSPAR value, %
DEVHI . . .	REAL*4	deviation of high (+1 sigma) density from COSPAR, %
DEVLO . . .	REAL*4	deviation of low (-1 sigma) density from COSPAR, %
DHGT . . .	REAL*4	terrain height factor for mountain wave magnitudes
DLATM . . .	REAL*4	dummy density argument used in calling ATMOS2
DLATP . . .	REAL*4	dummy density argument used in calling ATMOS2
DLONM . . .	REAL*4	dummy density argument used in calling ATMOS2
DLONP . . .	REAL*4	dummy density argument used in calling ATMOS2
DMINUS . . .	REAL*4	difference between average and low density
DPLUS . . .	REAL*4	difference between high and average density
DUSTA . . .	REAL*4	relative dust storm magnitude for diurnal variations
DUSTM . . .	REAL*4	relative dust storm magnitude for daily mean values
FACTHI . . .	REAL*4	ratio of high (+1 sigma) to average density
FACTLO . . .	REAL*4	ratio of average to low (-1 sigma) density
FACTOR . . .	REAL*4	boundary layer wind factor
FHI . . .	REAL*4	dummy high density factor for call to ATMOS2
FLO . . .	REAL*4	dummy low density factor for call to ATMOS2
FUG . . .	REAL*4	intermediate E-W component in wind calculations
FUGP . . .	REAL*4	intermediate E-W component in wind calculations
FVG . . .	REAL*4	intermediate N-S component in wind calculations
FVGP . . .	REAL*4	intermediate N-S component in wind calculations
GZ . . .	REAL*4	acceleration of gravity at current height
HLATM . . .	REAL*4	dummy scale height argument for call to ATMOS2
HLATP . . .	REAL*4	dummy scale height argument for call to ATMOS2
HLONM . . .	REAL*4	dummy scale height argument for call to ATMOS2
HLONP . . .	REAL*4	dummy scale height argument for call to ATMOS2
HLS . . .	REAL*4	horizontal scale for density perturbations
HSCALE . . .	REAL*4	pressure scale height
IFAUULT . . .	INTEGER*4	error flag for the PPND function
L . . .	INTEGER*4	error flag for the RANDOM function
MARSAU . . .	REAL*4	Sun-Mars orbital radius at current time
OHGT . . .	REAL*4	height above reference ellipsoid (for output purposes)
OHGTS . . .	REAL*4	height above local terrain (for output purposes)
PCOS . . .	REAL*4	COSPAR model atmospheric pressure
PERT . . .	REAL*4	mountain wave perturbation magnitude
PERTMAX . . .	REAL*4	maximum perturbation magnitude allowed by stability
PERTMIN . . .	REAL*4	minimum allowed perturbation magnitude
PI180 . . .	REAL*4	factor to convert degrees to radians
PLATM . . .	REAL*4	pressure south of position, for pressure gradients
PLATP . . .	REAL*4	pressure north of position, for pressure gradients
PLONM . . .	REAL*4	pressure east of position, for pressure gradients
PLONP . . .	REAL*4	pressure west of position, for pressure gradients
RLATM . . .	REAL*4	dummy radius from Mars center, used in ATMOS2 call
RLATP . . .	REAL*4	dummy radius from Mars center, used in ATMOS2 call
RLONM . . .	REAL*4	dummy radius from Mars center, used in ATMOS2 call
RLONP . . .	REAL*4	dummy radius from Mars center, used in ATMOS2 call
RSC . . .	REAL*4	radius from center of Mars to current position

SIGD. . . .	REAL*4	standard deviation for perturbations (% of mean)
SINWLAT. . .	REAL*4	sin of absolute value of latitude
SUNLAT. . .	REAL*4	latitude of sub-solar position
SUNLON. . .	REAL*4	West longitude of sub-solar position
TAVG. . . .	REAL*4	daily average surface temperature
TAVM. . . .	REAL*4	dummy average surface temperature in ATMOS2 call
TAVP. . . .	REAL*4	dummy average surface temperature in ATMOS2 call
TCOS. . . .	REAL*4	COSPAR model atmospheric temperature
TFAC. . . .	REAL*4	dummy density perturbation factor for call to ATMOS2
TFACOR. . .	REAL*4	density perturbation factor at base of thermosphere
THGT. . . .	REAL*4	local terrain height
TLATM. . . .	REAL*4	dummy temperature value for call to ATMOS2
TLATP. . . .	REAL*4	dummy temperature value for call to ATMOS2
TLOCAL. . .	REAL*4	local time in "Martian hours" (1/24th Sols)
TLONM. . . .	REAL*4	dummy temperature value for call to ATMOS2
TLONP. . . .	REAL*4	dummy temperature value for call to ATMOS2
TMAM. . . .	REAL*4	dummy maximum surface temperature in ATMOS2 call
TMAP. . . .	REAL*4	dummy maximum surface temperature in ATMOS2 call
TMAX. . . .	REAL*4	daily maximum surface temperature
TMIM. . . .	REAL*4	dummy minimum surface temperature in ATMOS2 call
TMIN. . . .	REAL*4	daily minimum surface temperature
TMIP. . . .	REAL*4	dummy minimum surface temperature in ATMOS2 call
VAR. . . .	REAL*4	output height variable for the OUTPUT file
VARX. . . .	REAL*4	x (1st) variable for plotable output files
VARY. . . .	REAL*4	y (2nd) variable for plotable output files
VISC. . . .	REAL*4	coefficient of molecular viscosity
VISCFAC. . .	REAL*4	viscous modification factor for winds
VLL. . . .	REAL*4	vertical scale for wind viscosity factor
VLS. . . .	REAL*4	vertical scale density for perturbations
WAVE. . . .	REAL*4	relative density perturbation from Zurek wave model
WIND. . . .	REAL*4	wind for use in perturbation magnitude
WLAT. . . .	REAL*4	latitude used for wind calculations
Z. . . .	REAL*4	height above ground (m), for boundary layer winds
Z0. . . .	REAL*4	surface roughness (m)
Z1. . . .	REAL*4	random variable, used in perturbation calculations
Z2. . . .	REAL*4	random variable, used in perturbation calculations
ZF. . . .	REAL*4	height of base of thermosphere
ZFACTOR. . .	REAL*4	height factor in vertical interpolation
ZT. . . .	REAL*4	dummy thermosphere base height, used in ATMOS2 call

### Methodology:

Datastep is the principal driver subroutine for stepping through the positions and evaluating the atmospheric variables. It starts by reading the next position from the trajectory input file or by automatically generating the next position from the increments in latitude, longitude, altitude and time.

Terrain height is obtained by calling the Terrain subroutine (DSTP 34), orbit parameters are evaluated by calling the ORBIT subroutine (DSTP 36), dust storm perturbation factors (dustM and dustA) are evaluated by calling subroutine Dustfact (DSTP 38) and the other mean atmospheric parameters are evaluated by calling ATMOS2 (DSTP 40). High (+1 sigma) and low (-1 sigma) density values are computed from the factors FACTHI and FACTLO (DSTP 43 - DSTP 57). A normally-distributed random variate is found, using RANDOM and PPND (DSTP 58 - DSTP 61). The vertical scale for the wind viscosity factor is set to the pressure scale height (DSTP 65). The vertical and horizontal scales for the density perturbations are found from

VLS = 8.0

DSTP 69

HLS = 30. + .01875\*CHGT\*\*2

DSTP 72

IF(HLS.GT.600.)HLS = 600.

DSTP 73

The components of the relative displacement between previous and current positions are computed

DELNS = DTR\*RSC\*(DELLAT)/HLS

DSTP 76

DELEW = -DTR\*RSC\*COS(DTR\*CLAT)\*DELLON/HLS

DSTP 77

DELZ = DELHGT/VLS

DSTP 78

and used to evaluate the correlation between the previous and current position

CORREL = Exp(-(Abs(DELNS) + Abs(DELEW) + Abs(DELZ)))

DSTP 81

Next, the wind components are computed from the horizontal pressure gradients (a Mars version of the geostrophic wind relations, referred to as the areostrophic winds; see discussion on computation of winds in the section "WIND PROFILES IN MARS-GRAM", of the Release 1 Technical Report, 1989; see Appendix B). The pressure gradients are computed by finite differences of the pressure across  $\pm 2.5^\circ$  latitude and longitude displacements from the current position, by calling ATMOS2 (longitude +  $2.5^\circ$  at DSTP 86; longitude -  $2.5^\circ$  at DSTP 91; latitude +  $2.5^\circ$  at DSTP104 and latitude -  $2.5^\circ$  at DSTP 113). The area-average terrain height, for use in the mountain-wave perturbation model, is evaluated with the Terrain function (DSTP 95 and DSTP117). For computing the pressure gradients, the distances corresponding to the 5 degree latitude or longitude displacements are computed at DSTP120 and DSTP129. The areostrophic wind components, computed from the pressure gradients are evaluated by

FUG = -(PLATP-PLATM)/(DELNS\*DENS)

DSTP137

FVG = (PLONP-PLONM)/(DELEW\*DENS)

DSTP138

[Release 1 Technical Report, equation (1); see Appendix B].

For modifications by molecular viscosity (relevant in the thermospheric region), viscosity factors are computed

VISC = BETA\*TEMP\*\*1.5/(TEMP + SVAL)

DSTP133

VISCFAC = VISC/(1.0E6\*DENS\*VLL\*\*2)

DSTP134

For absolute latitudes less than  $7.5^\circ$ , a special low-latitude wind model [Release 1 Technical Report, equations (2) and (3); see Appendix B] is used

FUGP = -4000.\*RSC\*SINWLAT\*(PLATP + PLATM - 2.\*PRES)/  
& (DENS\*COSWLAT\*DELNS\*DELNS)  
FVGP = 0.0

DSTP141

DSTP142

DSTP143

For absolute latitudes between  $7.5^\circ$  and  $15^\circ$ , winds are interpolated between the low-latitude and regular values

FUG = FUGP + (ABSWLAT-7.5)\*(FUG-FUGP)/7.5  
FVG = FVGP + (ABSWLAT-7.5)\*(FVG-FVGP)/7.5

DSTP145

DSTP146

For absolute latitudes greater than 75°, a special high-latitude relation [Release 1 Technical Report, equation (4); see Appendix B] is used

```

Cosfac = COSWLAT/Cos(pi180*75.)           DSTP154
FUG = FUG*COSWLAT*Cosfac                 DSTP155
FVG = FVG*COSWLAT*Cosfac                 DSTP156

```

Viscous-corrected wind components are computed by [Release 1 Technical Report, equations (6a) and (6b); see Appendix B]

```

DENOM = CORIOL**2 + VISCFAC**2           DSTP158

EWWIND = (CORIOL*FUG - VISCFAC*FVG)/DENOM DSTP160
NSWIND = (CORIOL*FVG + VISCFAC*FUG)/DENOM DSTP161

```

For altitudes within 1 km of the surface, boundary-layer modifications are applied [Release 1 Technical Report, equations (8) and (9); see Appendix B]

```

factor = (Sqrt(CD)/0.4)*Alog(z/z0)       DSTP172
if (factor .gt. 1.0) factor = 1.0        DSTP173
EWWIND = factor*EWWIND                   DSTP174
NSWIND = factor*NSWIND                   DSTP175

```

where  $z$  is the height above the surface (m), the drag coefficient is taken to be  $CD = 0.0015$  and the surface roughness is assumed to be  $z_0 = 0.03$  m.

For the mountain wave perturbation model [Release 1 Technical Report, equations (10) and (15); see Appendix B], the steps are:

(1) Compute the terrain height adjustment factor  $dhgt$  (local height above area-averaged terrain height, m) by

```

dhgt = 1000.*(thgt - areahgt)            DSTP184

dhgt = 2.0*dhgt                          DSTP187
If (dhgt .lt. 10.) dhgt = 10.             DSTP188
If (dhgt .gt. 2000.) dhgt = 2000.        DSTP189

```

(2) Compute the wind speed

```

Wind = Sqrt(NSWIND**2 + EWWIND**2)       DSTP191
If (Wind .lt. 1.0) Wind = 1.0            DSTP192

```

(3) Compute the viscous damping factor

```

Damping = 1.0E6*HLS*VISC*(Bruntf**3)*Hscale* DSTP194
& (1. - (DENS/densurf))/(12.56637*DENS*Wind**4) DSTP195
If (Damping .gt. 50.) Damping = 50.       DSTP196

```

(4) Compute the perturbation magnitude and insure that it does not exceed the maximum magnitude allowed by stability and that it is at least as large as a prescribed minimum value (dependent on height)

```

pert = FACTHI*dhgt*Exp(-Damping)                                DSTP198

pertmax = (500.*VLS*Bruntf**2/gz)*(1. + 0.5*VLS/Hscale)          DSTP199c
If (pertmax .gt. 0.5*VLS/Hscale) pertmax = 0.5*VLS/Hscale        DSTP199d
If (pert .gt. pertmax) pert = pertmax                             DSTP200
pertmin = 0.01 + 0.001*CHGT                                       DSTP201
If (pertmin .gt. 0.05) pertmin = 0.05                             DSTP202
If (pert .lt. pertmin) pert = pertmin                             DSTP203

```

(5) Between 75 km and the base of the thermosphere, interpolate between the mountain wave model and the magnitude derived from the Stewart thermosphere model at the base of the thermosphere

```

zfactor = (CHGT - 75.0)/(ZF - 75.0)                               DSTP207
pert = pert + zfactor*(tfactor - pert)                             DSTP208

```

(6) Values of DENSHI and DENSLO are computed, based on the mountain wave perturbation magnitudes

```

585  DENSHI = DENS*(1. + pert)                                     DSTP212
      DENSLO = DENS/(1. + pert)                                    DSTP213
      DPLUS = DENSHI - DENS                                         DSTP214
      DMINUS = DENS - DENSLO                                         DSTP215

```

The local time, in Martian hours = 1/24th Sols is computed from the longitude of the current position

```

TLOCAL = 12. + (SUNLON - CLON)/15.                                DSTP218
IF (TLOCAL .LT. 0.) TLOCAL = TLOCAL + 24.                          DSTP219
IF (TLOCAL .GT. 24.) TLOCAL = TLOCAL - 24.                          DSTP220

```

Height above the reference ellipsoid or above the local surface terrain height are evaluated and saved for output purposes

```

OHGT = CHGT                                                         DSTP223
OHGTS = CHGTS                                                         DSTP224
IF (OHGT .LE. -5.) THEN                                             DSTP225
  OHGT = thgt                                                         DSTP226
  OHGTS = 0.                                                         DSTP227
ENDIF                                                                DSTP228

```

The Zurek wave perturbation model (Section 4.3 of "The Mars Atmosphere: Observations and Model Profiles for Mars Missions", Report No. JSC-24455, David E. Pitts et al., eds., is used to add tidal wave perturbations

```

If (modpert .ne. 1) Call Wavepert(OHGT,CLAT,TLOCAL,DustM,DustA,    DSTP231
& wave,amp1,amp2)                                                  DSTP232

```

The Zurek tidal wave model and the mountain-wave model perturbation are added, with the mountain wave values treated as having the previously-computed correlation between the prior and current positions

```

RHO = CORREL*RHO + SQRT(1.0 - CORREL**2)*Z1                       DSTP235
IF (RHO.LT.0.0) DENSP = DENS*(1. + wave) + RHO*DMINUS            DSTP236

```



IF(RHO.GE.0.0)DENSP = DENS*(1. + wave) + RHO*DPLUS	DSTP237
If (DENSP .lt. 0.0)DENSP = 0.05*DENS	DSTP238

The standard deviation and DENSHI and DENSLO values are adjusted to reflect the Zurek wave perturbation values

SIGD = 50.*(DENSHI-DENSLO)/DENS	DSTP241
DENSHI = DENSHI + (amp1 + amp2)*DENS	DSTP243
DENSLO = DENSLO - (amp1 + amp2)*DENS	DSTP244
DENSP = 100.*(DENSP - DENS)/DENS	DSTP246

Deviations from the COSPAR reference atmosphere are computed (DSTP254b to DSTP254k). Descriptively formatted data are written to the LIST file (DSTP248 and DSTP255). Output to the various plotable-output (graphics-input) files (units 21-34) are written, according to the options selected (NVARX, NVARY, and logscale; DSTP264b through DSTP349).

**Subroutine:** DZDUST

**Code:** DZDS

**Description:** calculates the perturbation to ZF, the height of the base of the thermosphere, due to dust storms. Modified from the original Stewart subroutine, which assumed storms starting at  $L_s = 205$  and  $L_s = 275$  each year. Now uses the same starting  $L_s$  value as for lower atmosphere (if a dust storm case is selected).

**Called By:** ATMOS2, STEWART2

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

None

**Input Variables (not passed through commons):**

Name	Type	Description
INTENS. . .	REAL*4	dust storm intensity level (0.0 - 3.0)
ALS0. . . .	REAL*4	starting $L_s$ value for storm
LSUN. . . .	REAL*4	areocentric longitude of sun ( $L_s$ )

**Output Variables (not passed through commons):**

Name	Type	Description
DZ. . . . .	REAL*4	increase in height of base of thermosphere, due to dust storm, Stewart model method

**Local Variables (not passed through commons):**

Name	Type	Description
QA. . . . .	REAL*4	exponential decay factor for dust storm effect
DZA. . . . .	REAL*4	intermediate value for DZ calculation
DLS. . . . .	REAL*4	$L_s$ duration for dust storm effect (25 degrees of $L_s$ )
DLSA. . . .	REAL*4	difference in $L_s$ value from start of storm ( $L_s - L_{s0}$ )

#### Methodology:

This subroutine has been modified from the original subroutine of Stewart (which still appears in the code, but commented out). Instead of assuming two storms per Mars year (one starting at  $L_s = 205$ , another starting at  $L_s = 275$ ), DZDUST now uses the same  $L_s$  value for the beginning of the storm as is used for the lower altitude regions (based on user input value for  $L_{s0}$ ).

The  $L_s$  difference,  $L_s - L_{s0}$ , is put in the range 0-25, by the relation

$$DLSA = \text{AMOD}((LSUN - als0) + 720.0), 360.0)$$
 DZDS 27

The exponential time-decay factor is computed by

$$QA = \text{EXP}(-DLSA / DLS)$$
 DZDS 28

and the final displacement for the base of the thermosphere (km) is computed by

$$DZA = 5.0 * INTENS$$

DZDS 29

$$DZ = DZA * QA * (1.0 - QA^{**4}) * 1.869$$

DZDS 30

**Subroutine:** EScalc

**Code:** ESCL

**Description:** Computes short-term and long-term standard deviations from nominal densities in Stewart thermosphere model.

**Called By:** ATMOS2, STEWART2

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

None

**Input Variables (not passed through commons):**

Name	Type	Description
SIGMA. . .	REAL*4	long-term thermospheric variability factor
STDL . . .	REAL*4	short-term thermospheric variability factor

**Output Variables (not passed through commons):**

Name	Type	Description
ES . . . .	REAL*4	array for thermospheric variability factors

**Local Variables (not passed through commons):**

Name	Type	Description
I. . . . .	INTEGER*4	index for the ES array
EPS. . . .	REAL*4	intermediate array for ES calculations
SIG. . . .	REAL*4	array of coefficients for ES calculations

#### **Methodology:**

The short-term thermospheric variability factor, stdl, is read in the main (MarsGRAM) or SETUP routines. The long-term variability factor, SIGMA, is set by the calling value in the STEWART2 argument list (e.g. 0.0 at ATM2143, 1.0 at ATM2146 and ATM2164, or -1.0 at ATM2166).

Even-number indexed ES values (0, 2, 4, 6, 8, 10) are for long-term variability; odd-number indexed ES values (1, 3, 5, 7, 9, 11) are for short-term variability. ES(0) and ES(1) are for the dependence on solar activity (FBAR at STW2 25). ES(2) and ES(3) are for the exospheric temperature (TINF at STW2 46). ES(4) through ES(7) are for the atomic oxygen factors (FO at THRM 38 and AO at THRM 36). ES(8) and ES(9) are for the base-height of the thermosphere (ZF at ATM2137 and STW2 38) and the temperature at the base of the thermosphere (TF at STW2 47). ES(10) and ES(11) are for the dust storm effect on the thermosphere (DUST at ATM2135 and STW2 37).

The factors ES(1), ES(6) and ES(11) are set to zero in the Stewart thermosphere model, and have therefore been left out of the equations that they would otherwise appear in (i.e. they do not appear explicitly in lines STW2 25 [ES(1)], THRM 36 [ES(6)] or in ATM2135 or STW2 37 [ES(11)]).

Even-number indexed values of EPS are set to stdl; odd-number indexed values of EPS are set to SIGMA. The SIG array elements are set to assigned values and ES is computed as the product of EPS and SIG.

**Subroutine:** gamma

**Code:** GAMA

**Description:** Computes lapse rates ( $-dT/dz$ ) over the significant level areopotential height intervals, for a given latitude and  $L_s$  value.

**Called By:** ATMOS2

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

None

**Input Variables (not passed through commons):**

Name	Type	Description
ALAT. . . .	REAL*4	current latitude
ALS . . . .	REAL*4	areocentric longitude of the sun ( $L_s$ )

**Output Variables (not passed through commons):**

Name	Type	Description
GAM . . . .	REAL*4	lapse rate array (negative of temperature gradient)

**Local Variables (not passed through commons):**

Name	Type	Description
A . . . . .	REAL*4	coefficient for part of gamma depending only on latitude
A1. . . . .	REAL*4	gam(1) (0-5 km) coefficients for A term
A2. . . . .	REAL*4	gam(2) (5-15 km) coefficients for A term
A3. . . . .	REAL*4	gam(3) (15-30 km) coefficients for A term
B . . . . .	REAL*4	coefficient depending on latitude and sine of $L_s$
B1. . . . .	REAL*4	gam(1) (0-5 km) coefficients for B term
B2. . . . .	REAL*4	gam(2) (5-15 km) coefficients for B term
B3. . . . .	REAL*4	gam(3) (15-30 km) coefficients for B term
C . . . . .	REAL*4	coefficient depending on latitude and cosine of $L_s$
C1. . . . .	REAL*4	gam(1) (0-5 km) coefficients for C term
C2. . . . .	REAL*4	gam(2) (5-15 km) coefficients for C term
C3. . . . .	REAL*4	gam(3) (15-30 km) coefficients for C term
CALS. . . .	REAL*4	cosine of $L_s$ angle
F180. . . .	REAL*4	array of Fourier terms for $\pi/90$ times latitude
F240. . . .	REAL*4	array of Fourier terms for $\pi/120$ times latitude
I . . . . .	INTEGER*4	index value
PI120 . . .	REAL*4	$\pi/120$
PI180 . . .	REAL*4	$\pi/180$
PI90. . . .	REAL*4	$\pi/90$
SALS. . . .	REAL*4	sine of $L_s$ angle

**Methodology:**

Uses Fourier coefficients for (sine and cosine) terms in latitude and  $L_s$  angle. The temperature lapse rate ( $-dT/dz$ ) array, gam (in units of K/km), has 5 elements, one for each height interval between the significant levels: gam(1) applies to heights 0-5 km, gam(2) is for 5-15 km, gam(3) is for 15-30 km, gam(4) is for 30-50 km, and gam(5) applies to 50-75 km. The

upper two intervals are assumed to have fixed lapse rates:  $\text{gam}(4) = 0.9$  K/km and  $\text{gam}(5) = 0.4$  K/km. For the three lower levels, the gam values are computed by an equation of the form

$$\text{gam} = A + B \sin(Ls) + C \cos(Ls)$$

(GAMA 58, GAMA 68 and GAMA 78).

The A coefficient term is computed as a Fourier series, in terms of sines and cosines of multiples of  $\pi/90$  times the latitude (GAMA 54, GAMA 64, and GAMA 74). The B and C coefficient terms are computed as Fourier series, in terms of sines and cosines of multiples of  $\pi/120$  times the latitude (GAMA 55, GAMA 57, GAMA 65, GAMA 67, GAMA 75 and GAMA 77). Coefficients (A1, A2, A3, B1, B2, B3, C1, C2, and C3 arrays) are stored in data statements, indexed 0 through 8, for the constant coefficient and the 8 Fourier terms in the respective latitude series.

**Subroutine:** orbit

**Code:** ORBT

**Description:** Computes orbital radius of Mars from Sun, areocentric longitude of the sun (Ls) and the latitude and longitude of the sub-solar point on the Mars surface for a given time (expressed as a Julian date).

**Called By:** MarsGRAM (Main), Datastep, SETUP

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

None

**Input Variables (not passed through commons):**

Name	Type	Description
-----	-----	-----
XDATE . . .	REAL*8	Julian date for current time

**Output Variables (not passed through commons):**

Name	Type	Description
-----	-----	-----
LATSUN. . .	REAL*4	latitude of sub-solar point on Mars on Mars surface
LONSUN. . .	REAL*4	West longitude of sub-solar point on Mars surface
LSUBS . . .	REAL*4	areocentric longitude of the sun (like right ascension)
RADIUS. . .	REAL*4	magnitude of vector from Sun to orbital position of Mars

**Local Variables (not passed through commons):**

Name	Type	Description
-----	-----	-----
A0 thru A6	REAL*8	Fourier coefficients for RADIUS calculation
B0 thru B6	REAL*8	Fourier coefficients for LATSUN calculation
C0 thru C6	REAL*8	Fourier coefficients for LSUBS calculation
D0 thru D6	REAL*8	Fourier coefficients for LONSUN calculation
DATE. . . .	REAL*8	modified Julian date (xdate - 2442779. + 0.5)
DS. . . . .	REAL*8	intermediate value of LATSUN used for calculation
LON . . . .	REAL*8	intermediate value of LONSUN used for calculation
LON0. . . .	REAL*8	initial value of LONSUN
LS. . . . .	REAL*8	intermediate value of LSUBS used for calculation
LS0 . . . .	REAL*8	initial value of LSUBS
PER1. . . .	REAL*8	687 day period (used for LATSUN, LSUBS and RADIUS)
PER2. . . .	REAL*8	696 day period (used for LONSUN)
PERLON. . .	REAL*8	coefficient for linear increase of LONSUN with date
PERLS . . .	REAL*8	coefficient for linear increase of LSUBS with date
PI180 . . .	REAL*8	$\pi / 180$
RAD . . . .	REAL*8	intermediate value of RADIUS used for calculation
TIME1 . . .	REAL*8	current time variable with period = PER1
TIME2 . . .	REAL*8	current time variable with period = PER2
TWOPI . . .	REAL*8	$2 \pi$
XLON. . . .	REAL*8	part of LONSUN increasing linearly with date
XLS . . . .	REAL*8	part of LSUBS increasing linearly with date

#### **Methodology:**

Uses pre-computed coefficients in Fourier time series to compute LATSUN, LONSUN, LSUBS and RADIUS from the modified Julian date

DATE = XDATE - 2.442779d6 + 0.5d0

ORBT 18

The parts of LSUBS and LONSUN that increase linearly with the date are computed from

xls = ls0 + 3.60d2\*date/perls

ORBT 19

xlon = lon0 + 3.60d2\*(date - 2.922d3)/perlon

ORBT 20

The time variables for period 1 (687 day period) and period 2 (696 day period) are evaluated by

TIME1=DATE/PER1

ORBT 21

TIME2=DATE/PER2

ORBT 22

LSUBS (intermediate value LS), in degrees, is computed from

LS=C0+C1\*DSIN(TIME1)+C2\*DCOS(TIME1)+C3\*DSIN(2.0d0\*TIME1)

ORBT 23

& +C4\*DCOS(2.0d0\*TIME1)+C5\*DSIN(3.0d0\*TIME1)+C6\*DCOS(3.0d0\*TIME1)

ORBT 24

& +XLS

ORBT 25

LATSUN (intermediate value DS), in degrees, is computed from

DS=B0+B1\*DSIN(TIME1)+B2\*DCOS(TIME1)+B3\*DSIN(2.0d0\*TIME1)

ORBT 26

& +B4\*DCOS(2.0d0\*TIME1)+B5\*DSIN(3.0d0\*TIME1)+B6\*DCOS(3.0d0\*TIME1)

ORBT 27

LONSUN (intermediate value LON), in degrees, is computed from

LON=D0+D1\*DSIN(TIME2)+D2\*DCOS(TIME2)+D3\*DSIN(2.0d0\*TIME2)

ORBT 28

& +d4\*DCOS(2.0d0\*time2)+d5\*DSIN(3.0d0\*time2)+d6\*DCOS(3.0d0\*time2)

ORBT 29

& +xlon

ORBT 30

RADIUS (intermediate value RAD), in astronomical units (AU), is computed from

rad = a0 + a1\*DSIN(time1) + a2\*DCOS(time1)

ORBT 35

& + a3\*DSIN(2.0d0\*time1) + a4\*DCOS(2.0d0\*time1)

ORBT 36

& + a5\*DSIN(3.0d0\*time1) + a6\*DCOS(3.0d0\*time1)

ORBT 37

The Fourier coefficients (A0-A6, B0-B6, C0-C6 and D0-D6) are loaded in via data statements. Both LSUBS and LONSUN are put into the range 0 to 360 degrees.



**Function:** phasint

**Code:** PHSN

**Description:** Linear interpolation on phase angle, by vector components, for the phases of the wave perturbation field.

**Called By:** Wavepert

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

None

**Input Variables** (not passed through commons):

Name	Type	Description
DX . . . .	REAL*4	linear interpolation value (0-1)
OMEGA . . .	REAL*4	frequency for the phase angle interpolation
PH1 . . . .	REAL*4	phase angle at first position (location where DX=0)
PH2 . . . .	REAL*4	phase angle at second position (location where DX=1)

**Output Variables** (not passed through commons):

Name	Type	Description
PHASINT . .	REAL*4	interpolated phase angle at time corresponding input DX

**Local Variables** (not passed through commons):

Name	Type	Description
DPH . . . .	REAL*4	phi2 - phi1
X . . . . .	REAL*4	interpolated "x" vector component of phase
X1 . . . . .	REAL*4	"x" component of phase at time 1 [sin(omega*phi1)]
X2 . . . . .	REAL*4	"x" component of phase at time 2 [sin(omega*phi2)]
Y . . . . .	REAL*4	interpolated "y" vector component of phase
Y1 . . . . .	REAL*4	"y" component of phase at time 1 [cos(omega*phi1)]
Y2 . . . . .	REAL*4	"y" component of phase at time 2 [cos(omega*phi2)]

#### Methodology:

This routine is used to interpolate wave phase angle as a function of latitude or height, in the Zurek wave model (subroutine Wavepert). It treats phase angle as a circular variable, having "x" and "y" Cartesian vector components. The input parameter omega is the circular frequency for the latitude or height variation. Input values of phase angle (phi1 and phi2) corresponding to x and y component values

x1 = sin(omega*ph1)	PHSN	4
x2 = sin(omega*ph2)	PHSN	5
y1 = cos(omega*ph1)	PHSN	6
y2 = cos(omega*ph2)	PHSN	7

The interpolated values of the vector components are

x = x1 + (x2 - x1)*dx	PHSN	8
y = y1 + (y2 - y1)*dx	PHSN	9

The interpolated value of the phase angle is reconstructed from the vector components by

```
phasint = atan2(x,y)/omega
```

PHSN 10

The routine is also used to interpolate linearly on 24 hour local time variables, by the relations

```
dph = ph2 - ph1
```

PHSN 12

```
If (abs(dph) .gt. 12.)dph = dph - sign(24.,dph)
```

PHSN 13

```
phasint = ph1 + dph*dx
```

PHSN 14

**Function:** polecap

**Code:** POLC

**Description:** Computes radius (latitude degrees) of the edge of the polar cap from the pole, for a given areocentric longitude of sun (Ls), for either north polar cap or south polar cap.

**Called By:** Alb, Tsurface

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

None

**Input Variables (not passed through commons):**

Name	Type	Description
ALAT. . . .	REAL*4	latitude (+ for north pole, - for south pole)
ALS . . . .	REAL*4	areocentric longitude of the sun (Ls)

**Output Variables (not passed through commons):**

Name	Type	Description
POLECAP . .	REAL*4	polar cap radius (degrees of latitude)

**Local Variables (not passed through commons):**

Name	Type	Description
ALS0. . . .	REAL*4	polar cap phase in Ls angle
PI180 . . .	REAL*4	$\pi / 180$

#### **Methodology:**

Uses a sine wave in Ls to approximate the latitude progression and regression of the polar caps. The radial distance (in degrees of latitude) from the pole to the cap edge is computed by

$$\text{polecap} = 19. - 16.*\sin(\text{pi180}*(\text{als}-\text{als0}))$$

POLC 10

where als0 = 230 for the north polar cap and als0 = 50 for the south polar cap.

**Function:** PPND

**Code:** PPND

**Description:** Produces a normally-distributed deviate, for use in the random perturbation model.

**Called By:** Datastep

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

None

**Input Variables (not passed through commons):**

Name	Type	Description
p . . . . .	REAL*4	input value, from uniformly distributed random number

**Output Variables (not passed through commons):**

Name	Type	Description
IFault. . .	INTEGER*4	error flag
PPND. . . .	REAL*4	normally (Gaussian) distributed random variable

**Local Variables (not passed through commons):**

Name	Type	Description
A0 thru A3	REAL*4	coefficients used in computing PPND
B1 thru B4	REAL*4	coefficients used in computing PPND
C0 thru C3	REAL*4	coefficients used in computing PPND
D1 thru D2	REAL*4	coefficients used in computing PPND
HALF. . . .	REAL*4	1./2.
ONE . . . .	REAL*4	1.
Q . . . . .	REAL*4	$p - 1./2.$
R . . . . .	REAL*4	the square of Q
SPLIT . . .	REAL*4	0.42
ZERO. . . .	REAL*4	0.

**Methodology:**

Uses the method of algorithm AS 111, Applied Statistics (1977), Volume 26, page 118. The empirical coefficients (A0 through C3) are used to fit the normally-distributed value PPND corresponding to the lower tail area p of the normal error integral. The error flag ifault is set to 0 if  $0 < p < 1$ . Otherwise, ifault is set to 1 and PPND is set to 0.

**Subroutine:** Pressure

**Code:** PRES

**Description:** Computes an array of atmospheric pressures at the significant height levels, from the surface pressure, the terrain height, surface gravity, local radius of reference ellipsoid, and temperatures at the significant levels. Also computes the areographic altitudes,  $z(i)$ , corresponding to the areopotential altitudes,  $gph(i)$ , for the significant levels.

**Called By:** ATMOS2

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

None

**Input Variables (not passed through commons):**

Name	Type	Description
GAM . . . .	REAL*4	array of lapse rates across the significant levels
GZERO . . .	REAL*4	surface gravity
PSURF . . .	REAL*4	surface pressure
RBAR. . . .	REAL*4	gas constant
RREF. . . .	REAL*4	local radius of reference ellipsoid
T . . . . .	REAL*4	array of temperatures at the significant levels
THGT. . . .	REAL*4	terrain height above reference ellipsoid

**Output Variables (not passed through commons):**

Name	Type	Description
P . . . . .	REAL*4	array of pressures at the significant levels
Z . . . . .	REAL*4	array of areographic heights at the significant levels

**Local Variables (not passed through commons):**

Name	Type	Description
I . . . . .	INTEGER*4	array index
GOR . . . .	REAL*4	gravity divide by gas constant
DH. . . . .	REAL*4	height increment array between significant levels
GPH . . . .	REAL*4	areopotential height array of the significant levels

#### Methodology:

Evaluates the areographic altitudes,  $z(i)$ , that correspond to the areopotential heights,  $gph(i)$ , of the significant levels (0, 5, 15, 30, 50 and 75 areopotential km).

$$z(i) = (gph(i) + thgt) / (1. - (gph(i) + thgt) / rref) \quad \text{PRES 22}$$

Evaluates the pressure array  $p(i)$  at the significant level altitudes, using

$$p(i) = p(i-1) * \exp(-goR * \log(T(i-1) / T(i)) / gam(i)) \quad \text{PRES 25}$$

if the lapse rate,  $\text{gam}(i)$ , is not zero, or

$$p(i) = p(i-1) * \exp(-g_0 R * dh(i) / T(i-1))$$

PRES 27

if the lapse rate is zero.

**Subroutine:** PRSEAS

**Code:** PRSE

**Description:** Computes the relative seasonal variation in atmospheric pressure on the reference ellipsoid, at a given latitude and areocentric longitude of the sun (Ls).

**Called By:** ATMOS2, Psurface, STEWART2

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

None

**Input Variables** (not passed through commons):

Name	Type	Description
LAT . . . .	REAL*4	latitude of current position
LSUN. . . .	REAL*4	areocentric longitude of the sun (Ls)

**Output Variables** (not passed through commons):

Name	Type	Description
PR. . . . .	REAL*4	relative pressure variation with latitude and season at height of reference ellipsoid

**Local Variables** (not passed through commons):

Name	Type	Description
A1. . . . .	REAL*4	cos(Ls) coefficient
A11 . . . .	REAL*4	constant coefficient of A1 term
A12 . . . .	REAL*4	latitude coefficient of A1 term
A2. . . . .	REAL*4	cos(2 Ls) coefficient
A21 . . . .	REAL*4	constant coefficient of A2 term
A22 . . . .	REAL*4	latitude coefficient of A1 term
LAT2. . . .	REAL*4	square of latitude
PHI1. . . .	REAL*4	Ls phase angle of cos(Ls) term
PHI11 . . .	REAL*4	constant coefficient of PHI1 term
PHI12 . . .	REAL*4	latitude coefficient of PHI1 term
PHI2. . . .	REAL*4	Ls phase angle of cos(2 Ls) term
PHI21 . . .	REAL*4	constant coefficient of PHI2 term
PHI22 . . .	REAL*4	latitude coefficient of PHI2 term
PI180 . . .	REAL*4	$\pi / 180$

#### Methodology:

Computes amplitudes of cos(Ls) and cos(2 Ls) terms as a function of the square of the latitude by

```
a1 = a11 + a12*Lat2
a2 = a21 + a22*Lat2
```

PRSE 10  
PRSE 11

Computes Ls phase angles of cos(Ls) and cos(2 Ls) terms by

```
phi1 = phi11 + phi12*Lat2
phi2 = phi21 + phi22*Lat2
```

PRSE 12  
PRSE 13

Compute the relative pressure, as a function of latitude and  $L_s = L_{\text{sun}}$  by

```
PR = 1. + a1*cos(pi180*(Lsun - phi1)) +  
& a2*cos(2.*pi180*(Lsun - phi2))
```

```
PRSE 14  
PRSE 15
```



**Subroutine:** Psurface

**Code:** PSRF

**Description:** Computes the daily average surface pressure and local surface pressure at a given latitude and longitude for a given areocentric longitude of the sun (Ls), and daily average surface temperature.

**Called By:** ATMOS2

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

None

**Input Variables** (not passed through commons):

Name	Type	Description
ALS . . . .	REAL*4	areocentric longitude of the sun (Ls)
DUSTA . . .	REAL*4	dust storm effect of diurnal amplitude
DUSTM . . .	REAL*4	dust storm effect on daily mean values
GAMMA . . .	REAL*4	local temperature lapse rate (K/km)
GZERO . . .	REAL*4	surface gravity
RBAR . . . .	REAL*4	gas constant
SITLA . . .	REAL*4	local site latitude
SITLO . . .	REAL*4	local site longitude
SUNLON . . .	REAL*4	longitude of sub-solar point
TAVG . . . .	REAL*4	daily average surface temperature
THGT . . . .	REAL*4	local terrain height

**Output Variables** (not passed through commons):

Name	Type	Description
PAVG . . . .	REAL*4	array of daily average pressures at significant levels
PSURF . . .	REAL*4	daily average local surface pressure

**Local Variables** (not passed through commons):

Name	Type	Description
A11 . . . .	REAL*4	diurnal amplitude coefficient
A12 . . . .	REAL*4	diurnal amplitude coefficient
A21 . . . .	REAL*4	semi-diurnal amplitude coefficient
A22 . . . .	REAL*4	semi-diurnal amplitude coefficient
ABSLAT . . .	REAL*4	absolute value of latitude
ALSM60 . . .	REAL*4	Ls - 60 degrees, converted to radians
AMP1 . . . .	REAL*4	amplitude of diurnal dust effect
AMP2 . . . .	REAL*4	amplitude of semi-diurnal dust effect
C0 thru C2	REAL*4	coefficients in pressure/temperature ratio
COSLAT . . .	REAL*4	cosine of latitude
COSLS . . . .	REAL*4	cosine of Ls - 60
D0 thru D2	REAL*4	coefficients in pressure/temperature ratio
EXPONENT . .	REAL*4	exponent in pressure variation with temperature
FACTOR . . .	REAL*4	coefficient in latitude and seasonal daily pressure
FREQ . . . .	REAL*4	diurnal frequency (15 degrees per Mars hour)
H11 . . . .	REAL*4	diurnal phase coefficient
H12 . . . .	REAL*4	diurnal phase coefficient
H21 . . . .	REAL*4	semi-diurnal phase coefficient
H22 . . . .	REAL*4	semi-diurnal phase coefficient
NMALS . . . .	REAL*4	square of 90 - absolute latitude
NMLS . . . .	REAL*4	square of 90 - latitude
NPLS . . . .	REAL*4	square of 90 + latitude
PH1 . . . .	REAL*4	time phase of diurnal surface pressure variation

PH2 . . . .	REAL*4	time phase of semi-diurnal surface pressure variation
PI180 . . .	REAL*4	$\pi / 180$
POTAVG. . .	REAL*4	annual average pressure/temperature ratio
PR. . . . .	REAL*4	seasonally and latitudinally dependent relative pressure
PREF. . . .	REAL*4	daily average temperature on reference ellipsoid
RREF. . . .	REAL*4	local radius of reference ellipsoid
SINLS . . .	REAL*4	sine of $L_s$
TBAR. . . .	REAL*4	estimated annual average temperature versus latitude
TLOCAL. . .	REAL*4	local time in Mars hours (1/24th Sols)
TREF. . . .	REAL*4	temperature in conversion of pressure to terrain height
XLAT. . . .	REAL*4	current latitude in radians

### Methodology:

Compute local radius of reference ellipsoid and surface gravity at current latitude, using the RELLIPS subroutine. Evaluates the annual average of the pressure/temperature ratio on the reference ellipsoid

If (abslat .lt. 55.) then	PSRF 29
potavg = 0.5*(2.*C0 + C1*(npls+nmls) + C2*(npls**2	PSRF 30
& +nmls**2))	PSRF 31
Else	PSRF 32
potavg = 0.5*(D0 + D1*abslat + D2*abslat**2 +	PSRF 33
& C0 + C1*nmals + C2*nmals**2)	PSRF 34
Endif	PSRF 35

Computes the annual average temperature as a function of latitude

Tbar = (((0.525161E-6*sitla - 0.263317E-5)*sitla	PSRF 37
& - 0.0116584)*sitla + 0.0334196)*sitla + 216.54	PSRF 38

Uses the PRSEAS subroutine to get the relative pressure for the given latitude and  $L_s$  value, then converts this to actual daily average pressure at the height of the reference ellipsoid

Call PRSEAS(als,sitla,pr)	PSRF 40
factor = 1.3854 - 3.59437E-5*sitla**2	PSRF 43
pref = factor*pr*potavg*Tbar	PSRF 44

Converts pressure on the reference ellipsoid to pressure on the local terrain surface

If (abs(gamma) .lt. 0.001) then	PSRF 46
pavg = pref*exp(-1000.*gzero*thgt/(Rbar*Tavg))	PSRF 47
Else	PSRF 48
Tref = Tavg + gamma*thgt	PSRF 49
exponent = -1000.*gzero/(Rbar*gamma)	PSRF 50
pavg = pref*((Tref/Tavg)**exponent)	PSRF 51
Endif	PSRF 52

Computes the effects of dust storm (if any) on the diurnal average pressure

pavg = pavg + (61.082*sin(2.*pi180*sitla)	PSRF 54
& - 10.837*sin(4.*pi180*sitla))*dustM	PSRF 55

Evaluates the local time in Mars hours

```
tlocal = 12. + (sunlon - sitlo)/15.
If (tlocal .lt. 0.) tlocal = tlocal + 24.
If (tlocal .gt. 24.) tlocal = tlocal - 24.
```

PSRF 57  
PSRF 58  
PSRF 59

Computes the amplitude (amp1, N/m<sup>2</sup>) and phase (ph1, hours) of the diurnal variation in surface pressure

```
sinLs = sin(pi180*als)
A11 = 12.60 - 0.118*sitla
A12 = -0.60 - 0.063*sitla
amp1 = A11 + A12*sinLs
H11 = 7.769 - 0.05769*sitla
H12 = 3.077 + 0.001923*sitla
ph1 = H11 - H12*sinLs
```

PSRF 61  
PSRF 62  
PSRF 63  
PSRF 64  
PSRF 65  
PSRF 66  
PSRF 67

Computes the amplitude (amp2, N/m<sup>2</sup>) and phase (ph2, hours) of the semi-diurnal variation in surface pressure

```
A21 = 7.982 - 0.022*sitla
A22 = -5.219 + 0.033*sitla
amp2 = A21 + A22*sinLs
H21 = 11.635 - 0.02885*sitla
H22 = -0.135 + 0.02885*sitla
alsm60 = pi180*(als-60.)
cosLs = cos(alsm60)
ph2 = H21 + H22*cosLs
```

PSRF 69  
PSRF 70  
PSRF 71  
PSRF 72  
PSRF 73  
PSRF 74  
PSRF 75  
PSRF 76

Adds the dust storm effects on the diurnal and semi-diurnal amplitudes

```
amp1 = amp1 + (1.32 + 13.56*coslat)*dustA
amp2 = amp2 + (33.33*exp(-.618727E-3*sitla**2))*dustA
```

PSRF 80  
PSRF 81

Evaluates the local surface pressure as the daily average value plus the diurnal and semi-diurnal variations of pressure about the daily average

```
psurf = pavg + amp1*cos(freq*(tlocal-ph1))
& + amp2*cos(2.*freq*(tlocal-ph2))
```

PSRF 85  
PSRF 86

**Function:** Random

**Code:** RAND

**Description:** Returns a pseudo-random number, rectangularly distributed between 0 and 1.

**Called By:** MarsGRAM (Main), Datastep, SETUP

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

RANDCOM

**Input Variables (not passed through commons):**

Name	Type	Description
-----	-----	-----
None		

**Output Variables (not passed through commons):**

Name	Type	Description
-----	-----	-----
L . . . . .	INTEGER*4	error flag
RANDOM. . .	REAL*4	uniformly distributed random variate (0 - 1)

**Local Variables (not passed through commons):**

Name	Type	Description
-----	-----	-----
ONE . . . .	REAL*4	1.0
ZERO. . . .	REAL*4	0.0

**Methodology:**

Returns a pseudo random variate, uniformly distributed between 0 and 1, using the method of Algorithm AS 183, Applied Statistics (1982), Volume 31, page 188. Uses the integer variables IX, IY and IZ, passed through common RANDCOM. Successive values of IX, IY and IZ are computed by

IX = 171 * Mod(IX, 177) - 2 * (IX / 177)	RAND 19
IY = 172 * Mod(IY, 176) - 35 * (IY / 176)	RAND 20
IZ = 170 * Mod(IZ, 178) - 63 * (IZ / 178)	RAND 21
If (IX .lt. 0) IX = IX + 30269	RAND 23
If (IY .lt. 0) IY = IY + 30307	RAND 24
If (IZ .lt. 0) IZ = IZ + 30323	RAND 25

The pseudo-random deviate value is computed from

Random = Amod(float(IX) / 30269.0 + float(IY) / 30307.0 +	RAND 37
& float(IZ) / 30323.0, one)	RAND 38

**Subroutine:** RELLIPS

**Code:** RLPS

**Description:** Calculates the reference radius of Cain et al's 6.1 mbar reference ellipsoid, for a given latitude. Also computes the acceleration of gravity for a given altitude above the reference ellipsoid at that latitude.

**Called By:** MarsGRAM (Main), ATMOS2, Datastep, Psurface, STEWART2, THERMOS, SETUP

**Common Blocks Used (See Table 2-3 for a list of variables in common blocks):**

None

**Input Variables (not passed through commons):**

Name	Type	Description
LAT . . . .	REAL*4	current latitude (degrees)
Z . . . . .	REAL*4	current height (km)

**Output Variables (not passed through commons):**

Name	Type	Description
GZ. . . . .	REAL*4	acceleration of gravity at height z (m/s <sup>2</sup> )
RREF. . . .	REAL*4	local radius of reference ellipsoid (km)

**Local Variables (not passed through commons):**

Name	Type	Description
A . . . . .	REAL*4	largest equatorial radius of reference ellipsoid
AB. . . . .	REAL*4	square root of product of A and B
B . . . . .	REAL*4	smallest equatorial radius of reference ellipsoid
C . . . . .	REAL*4	polar radius of reference ellipsoid
GM. . . . .	REAL*4	gravitational constant time mass of Mars
J2. . . . .	REAL*4	coefficient of 1st non-spherical component of gravity
P2. . . . .	REAL*4	latitude part of non-spherical component of gravity
RADEG . . .	REAL*4	180 / $\pi$
RZ. . . . .	REAL*4	radius to current height
TLAT. . . .	REAL*4	tangent of latitude
XX. . . . .	REAL*4	square of x component of local ellipsoid radius
YY. . . . .	REAL*4	square of y component of local ellipsoid radius

#### Methodology:

Uses geometry of an ellipsoid and the reference radii A = 3394.67 km, B = 3393.21 km, and C = 3376.78 to compute the local radius of the reference ellipsoid

XX = (AB * C)**2 / (C**2 + (AB * TLAT)**2)	RLPS 15
YY = XX * TLAT**2	RLPS 16
Rref = SQRT(XX + YY)	RLPS 17

Compute the acceleration of gravity at altitude z, by the method of Seiff (Advances in Space Research, Volume 2, 1982, pages 3-17). This includes the spherically

symmetric gravitational component and the first (J2) non-spherically symmetric component

GM = 4.28282E7	RLPS 19
J2 = 0.001965	RLPS 20
P2 = 1.5*sin(LAT / RADEG)**2 - 0.5	RLPS 21
Rz = Rref + z	RLPS 22
gz = (GM/Rz**2)*(1. - 3.*J2*((AB/Rz)**2)*P2)	RLPS 23

**Subroutine:** Stratos

**Code:** STRA

**Description:** Interpolates between z75, the areographic height for the 75 km areopotential significant level, and ZF, the base of the Stewart thermosphere. Computes temperature, pressure, density, scale height, and temperature gradient at a given height z between these two levels.

**Called By:** ATMOS2

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

None

**Input Variables** (not passed through commons):

Name	Type	Description
GZ. . . . .	REAL*4	acceleration of gravity at current altitude
M75 . . . . .	REAL*4	molecular weight at 75 km areopotential km
MF. . . . .	REAL*4	molecular weight at base of thermosphere
P75 . . . . .	REAL*4	pressure at 75 km areopotential km
PF. . . . .	REAL*4	pressure at base of thermosphere
RREF. . . . .	REAL*4	local radius of reference ellipsoid
RSTAR . . . .	REAL*4	gas constant
T50 . . . . .	REAL*4	temperature at 50 km areopotential km
T75 . . . . .	REAL*4	temperature at 75 km areopotential km
TF. . . . .	REAL*4	temperature at base of thermosphere
Z . . . . .	REAL*4	current altitude (km)
Z50 . . . . .	REAL*4	areographic height at 50 km areopotential km
Z75 . . . . .	REAL*4	areographic height at 75 km areopotential km
ZF. . . . .	REAL*4	height at base of thermosphere

**Output Variables** (not passed through commons):

Name	Type	Description
DZ. . . . .	REAL*4	atmospheric density at current altitude
HZ. . . . .	REAL*4	scale height at current altitude
PZ. . . . .	REAL*4	atmospheric pressure at current altitude
TGRAD . . . .	REAL*4	vertical temperature gradient (K/km)
TZ. . . . .	REAL*4	atmospheric temperature at current altitude

**Local Variables** (not passed through commons):

Name	Type	Description
DH. . . . .	REAL*4	height interpolation factor $(H - H75)/(HF - H75)$
EXPON . . . .	REAL*4	exponent in pressure versus temperature dependence
GAM1. . . . .	REAL*4	temperature gradient between H75 and HM
GAM2. . . . .	REAL*4	temperature gradient between HM and HF
GOR . . . . .	REAL*4	gravity divided by gas constant
H . . . . .	REAL*4	areopotential altitude corresponding to Z
H50 . . . . .	REAL*4	areopotential altitude corresponding to Z50
H75 . . . . .	REAL*4	areopotential altitude corresponding to Z75
HF. . . . .	REAL*4	areopotential altitude corresponding to ZF
HFP . . . . .	REAL*4	HF adjusted by molecular weight ratio
HM. . . . .	REAL*4	midpoint between H75 and HFP
HP. . . . .	REAL*4	H adjusted by molecular weight ratio
M . . . . .	REAL*4	molecular weight at height Z
PM. . . . .	REAL*4	pressure at midpoint height HM
TM. . . . .	REAL*4	temperature at midpoint height HM

## Methodology:

Uses input values of  $z_{75}$  and  $z_{50}$ , the areographic altitudes above the reference ellipsoid corresponding to 75 km and 50 km areopotential altitude above local surface, to compute  $H_{75}$  and  $H_{50}$ , the areopotential altitudes above the reference ellipsoid, corresponding to  $z_{75}$  and  $z_{50}$

$$\begin{aligned} H_{75} &= z_{75} / (1. + z_{75} / r_{ref}) & \text{STRA } 8 \\ H_{50} &= z_{50} / (1. + z_{50} / r_{ref}) & \text{STRA } 9 \end{aligned}$$

Finds  $H_F$ , the areopotential altitude corresponding to  $z_F$ , areographic altitude of the base of the thermosphere

$$H_F = z_F / (1. + z_F / r_{ref}) \quad \text{STRA } 12$$

Computes  $H$ , the areopotential altitude corresponding to the current areographic altitude  $z$ , relative to the reference ellipsoid

$$H = z / (1. + z / r_{ref}) \quad \text{STRA } 15$$

Interpolates on height to get  $M$ , the molecular weight at height  $z$

$$\begin{aligned} dH &= (H - H_{75}) / (H_F - H_{75}) & \text{STRA } 17 \\ M &= M_{75} + (M_F - M_{75}) * dH & \text{STRA } 18 \end{aligned}$$

Adjusts the heights  $H_F$  and  $H$  by the molecular weight ratio

$$\begin{aligned} H_{FP} &= M_F * H_F / M_{75} & \text{STRA } 20 \\ H_P &= M * H / M_{75} & \text{STRA } 21 \end{aligned}$$

Finds  $H_M$ , the midpoint (molecular weight adjusted) height between  $z_{75}$  and  $z_F$

$$H_M = 0.5 * (H_{FP} + H_{75}) \quad \text{STRA } 23$$

Uses quadratic height interpolation (fitting the temperature at heights  $H_{50}$ ,  $H_{75}$  and  $H_{FP}$ ) to get the temperature  $T_M$  at the midpoint height  $H_M$

$$\begin{aligned} T_M &= -0.25 * T_{50} * (H_{FP} - H_{75})^2 / ((H_{75} - H_{50}) * (H_{FP} - H_{50})) & \text{STRA } 25 \\ &\& + 0.5 * T_{75} * (H_M - H_{50}) / (H_{75} - H_{50}) + 0.5 * T_F * (H_M - H_{50}) / (H_{FP} - H_{50}) & \text{STRA } 26 \\ \text{If } (T_M \text{ eq. } T_{75}) & T_M = T_{75} + 1. & \text{STRA } 27 \\ \text{If } (T_M \text{ eq. } T_F) & T_M = T_F - 1. & \text{STRA } 28 \end{aligned}$$

Computes the temperature gradients for the two layers  $H_{75}$  to  $H_M$  and  $H_M$  to  $H_F$

$$\begin{aligned} \text{gam1} &= (T_M - T_{75}) / (H_M - H_{75}) & \text{STRA } 30 \\ \text{gam2} &= (T_F - T_M) / (H_{FP} - H_M) & \text{STRA } 31 \end{aligned}$$

Find the exponent factors for pressure variation in the two layers



```

goR = Alog(p75/pF)/(Alog(TM/T75)/gam1 + Alog(TF/TM)/gam2)      STRA 33
pM = p75*(T75/TM)**(goR/gam1)                                    STRA 34

```

Interpolates for temperature Tz and pressure pz at height z, using linear temperature gradients in whichever of the two layers the height z falls (H75 to HM or HM to HFP)

```

If (HP .lt. HM)Then                                             STRA 37
  tgrad = gam1                                                  STRA 38
  Tz = T75 + tgrad*(HP - H75)                                    STRA 39
  expon = goR/gam1                                              STRA 40
  pz = p75*(T75/Tz)**expon                                      STRA 41
Else                                                            STRA 42
  tgrad = gam2                                                  STRA 43
  Tz = TM + tgrad*(HP - HM)                                     STRA 44
  expon = goR/gam2                                              STRA 45
  pz = pM*(TM/Tz)**expon                                        STRA 46
Endif                                                            STRA 47

```

Convert the units of the temperature gradient to K/km

```

tgrad = 0.001*tgrad                                           STRA 49

```

Computes the density dz at height z from the perfect gas law

```

100 dz = M*pz/(Rstar*Tz)                                       STRA 51

```

Calculates the scale height Hz at height z by the relation

```

Hz = 0.001*Rstar*Tz/(gz*M)                                     STRA 53

```

**Subroutine:** STEWART2

**Code:** STW2

**Description:** Stewart thermosphere model for computing global mean temperature and density at a given areocentric longitude of the sun (Ls). Computes effects due to solar activity influence and effects due to dust storm (if one is in progress).

**Called By:** ATMOS2

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

THERM

**Input Variables (not passed through commons):**

Name	Type	Description
ALSO . . . .	REAL*4	Ls value at start of dust storm (if any)
CHGT . . . .	REAL*4	current height
INTENS . . .	REAL*4	dust storm intensity (0.0 - 3.0)
IU0 . . . .	INTEGER*4	unit number for screen output of messages
LAT . . . .	REAL*4	current latitude
LST . . . .	REAL*4	local solar time
LSUN . . . .	REAL*4	areocentric longitude of the sun (Ls)
RAUI . . . .	REAL*4	Mars orbital radius in astronomical units
RSTAR . . . .	REAL*4	gas constant
SIGMA . . . .	REAL*4	standard deviation for long term thermosphere variations

**Output Variables (not passed through commons):**

Name	Type	Description
H . . . . .	REAL*4	pressure scale height
MOLWTG . . .	REAL*4	molecular weight
TOTALMDZ . .	REAL*4	total atmospheric mass density
TOTALPRZ . .	REAL*4	total atmospheric pressure
TZ . . . . .	REAL*4	atmospheric temperature

**Local Variables (not passed through commons):**

Name	Type	Description
DR . . . . .	REAL*4	seasonal correction to the height of the base of the thermosphere
DUST . . . .	REAL*4	dust correction to the height of the base of the thermosphere
ES . . . . .	REAL*4	array of thermospheric correction factors
FBAR . . . .	REAL*4	mean value of 10.7 cm solar flux at Earth position (1 AU)
FBARR . . . .	REAL*4	mean value of 10.7 cm solar flux at Mars position
FLAG . . . .	INTEGER*4	test flag, set to 1 to get diagnostic output
GZ . . . . .	REAL*4	acceleration of gravity at current height
MDZ . . . . .	REAL*4	atmospheric mass density
NDZ . . . . .	REAL*4	atmospheric number density
PFAC . . . .	REAL*4	relative pressure factor for season and latitude
PRZ . . . . .	REAL*4	atmospheric pressure
RAU . . . . .	REAL*4	Mars orbital radius (in AU)
RF . . . . .	REAL*4	total radius to position (height plus ellipsoid radius)
RREF . . . .	REAL*4	local radius of reference ellipsoid
SMA . . . . .	REAL*4	semi-major axis of Mars orbit
TF . . . . .	REAL*4	temperature at the base of the thermosphere
TINF . . . .	REAL*4	exospheric temperature
TO . . . . .	REAL*4	factor used in correction to ZF for seasonal variation

TOTALNDZ. . .	REAL*4	total atmospheric number density
ZF. . . . .	REAL*4	height of the base of the thermosphere
ZZF. . . . .	REAL*4	difference between current height and ZF

### Methodology:

The Stewart thermosphere model (including subroutine STEWART2 and the associated subroutines THERMOS, DZDUST, Escalc, PRSEAS and RELLIPS) was converted to FORTRAN code from the Pascal version listed in Appendix B of "The Mars Atmosphere: Observations and Model Profiles for Mars Missions", David E. Pitts et al., eds., JSC-24455. The model has also been discussed, and given in IDL code, by Ian Stewart, Laboratory for Atmospheric and Space Physics, University of Colorado, Final Report JPL PO # NQ-802429.

Use the EScalc subroutine to evaluate the ES array of thermospheric variability factors for the input standard deviations for short term (std1) and long term (SIGMA) variability

Call EScalc(std1,SIGMA,ES)	STW2 21
----------------------------	---------

Adjust the 10.7 cm solar flux for long-term mean value, with ES(0)

FBAR = F107 * EXP(ES(0))	STW2 25
--------------------------	---------

Convert the 10.7 cm solar flux to the orbital position of Mars

FBARR = FBAR / (RAU**2)	STW2 29
-------------------------	---------

Call RELLIPS to get the acceleration of gravity, GZ, and the local radius of the reference ellipsoid, RREF. Call PRSEAS to get the relative pressure factor for the given value of Ls (LSUN) and latitude.

CALL RELLIPS( LAT, RREF, CHGT, GZ)	STW2 30
CALL PRSEAS(LSUN, LAT, PFAC)	STW2 31

Calculate DR, the seasonal correction to the height of the base of the thermosphere

TO = 220.0 * SMA / RAU	STW2 33
DR = (TO / 19.51) * ALOG(PFAC)	STW2 34

Evaluate the dust storm correction and compute ZF, the height of the base of the thermosphere, and ZZF, the current height relative to the base of the thermosphere

CALL DZDUST( LSUN, als0, INTENS, DUST)	STW2 36
DUST = DUST * EXP(ES(10))	STW2 37
ZF = (124.4 * SMA / RAU) * EXP(ES(8) + ES(9)) + DR + DUST	STW2 38
ZZF = CHGT - ZF	STW2 39

Find the total radius (radius of reference ellipsoid plus the height), the exospheric temperature, TINF, and the temperature of the base of the thermosphere, TF

RF = RREF + ZF	STW2 45
TINF = 4.11 * (11.0 + FBARR) * EXP(ES(2) + ES(3))	STW2 46

TF = (170.0 \* SMA / RAU) \* EXP(ES(8) + ES(9))

STW2 47

Call the THERMOS subroutine to get the remaining variables computed by the Stewart model

CALL THERMOS(FLAG, ES, TINF, TF, LAT, LST, ZF, RF, ZZF, TOTALPRZ, STW2 58  
& TOTALNDZ, TZ, MOLWTG, PRZ, NDZ, MDZ, TOTALMDZ ,iu0) STW2 59

Calculate H, the scale height, in km

H = RSTAR\*TZ/(1000.\*MOLWTG\*GZ)

STW2 61

Convert the atmospheric pressure value to N/m\*\*2

TOTALPRZ = TOTALPRZ\*1.0E5

STW2 63

Convert the atmospheric density value to kg/m\*\*3

TOTALMDZ = TOTALMDZ\*1000.

STW2 65

**Function:** Tdiurnal

**Code:** TDIR

**Description:** Computes local surface temperature from the daily maximum and minimum surface temperature and the site-sun longitude separation.

**Called By:** Tsurface

**Common Blocks Used (See Table 2-3 for a list of variables in common blocks):**

None

**Input Variables (not passed through commons):**

Name	Type	Description
DLO . . . .	REAL*4	longitude difference from current position to sun
TMAX. . . .	REAL*4	daily maximum surface temperature
TMIN. . . .	REAL*4	daily minimum surface temperature

**Output Variables (not passed through commons):**

Name	Type	Description
TDIURNAL. .	REAL*4	local surface temperature at current time

**Local Variables (not passed through commons):**

Name	Type	Description
COSFAC. . .	REAL*4	cosine factor in diurnal variation (+1 or -1)
DT. . . . .	REAL*4	diurnal temperature interpolation factor
OFFSET. . .	REAL*4	longitude offset in diurnal temperature interpolation
PERIOD. . .	REAL*4	effective period for diurnal interpolation
PI180 . . .	REAL*4	$\pi / 180$

**Methodology:**

Divides site-sun longitude difference into five ranges (-180 to -102.19 degrees, -102.19 to -48.6 degrees, -48.6 to +43.8 degrees, +43.8 to +111.5 degrees, and +111.5 to +180 degrees). Finds values of cosfac, period and offset for whichever range is appropriate, based on input value of site-sun longitude difference. Computes the diurnal temperature shape factor dT for the values of cosfac, period and offset thus determined

dT = .5*(1. + cosfac*cos(pi180*period*(dlo + offset)))	TDIR 26
dT = (-0.3455*dT + 1.3455)*dT	TDIR 27

Evaluates the local surface temperature, from the interpolation factor dT and the daily maximum and minimum temperature values

Tdiurnal = Tmin + (Tmax - Tmin)*dT	TDIR 29
------------------------------------	---------

**Function:** Terrain

**Code:** TERN

**Description:** Computes terrain height, relative to reference ellipsoid, for the given array of terrain height data, at a given latitude and longitude.

**Called By:** MarsGRAM (Main), Datastep, SETUP

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

TERHGT

**Input Variables (not passed through commons):**

Name	Type	Description
ALAT. . . .	REAL*4	current latitude (degrees)
ALON. . . .	REAL*4	current West longitude (degrees)

**Output Variables (not passed through commons):**

Name	Type	Description
TERRAIN . .	REAL*4	terrain height (km)

**Local Variables (not passed through commons):**

Name	Type	Description
DLAT. . . .	REAL*4	latitude increment between terrain data base values
DLO. . . .	REAL*4	longitude increment between terrain data base values
F1 thru F4	REAL*4	terrain heights at four corners of grid containing the desired location
ILAT. . . .	INTEGER*4	latitude index of terrain height data array
ILON. . . .	INTEGER*4	longitude index of terrain height data array
NLAT. . . .	INTEGER*4	number of latitude grids in data array
NLO. . . .	INTEGER*4	number of longitude grids in data array
RADVL1. . .	REAL*4	normalized distance parameter from Viking 1 site
RADVL2. . .	REAL*4	normalized distance parameter from Viking 2 site
TERR. . . .	REAL*4	intermediate value of interpolated terrain height
VL1HGT. . .	REAL*4	Viking 1 site terrain height
VL1LAT. . .	REAL*4	Viking 1 site latitude
VL1LO. . .	REAL*4	Viking 1 site longitude
VL2HGT. . .	REAL*4	Viking 2 site terrain height
VL2LAT. . .	REAL*4	Viking 2 site latitude
VL2LO. . .	REAL*4	Viking 2 site longitude
XLO. . . .	REAL*4	relative longitude from interpolation grid corner
YLAT. . . .	REAL*4	relative latitude from interpolation grid corner

#### Methodology:

Computes the latitude and longitude increments between the terrain data bases grid points

dlat = 180./(nlat-1.)	TERN 14
dlon = 360./(nlon-1.)	TERN 15

Finds the latitude and longitude index values of the interpolation lat-lon rectangle that contains the desired location

ilat = 1 + int((90.+alat)/dlat)	TERN 17
If (ilat .gt. nlat-1)ilat = nlat-1	TERN 18
ilon = 1 + int(alon/dlon)	TERN 20
If (ilon .gt. nlon-1)ilon = nlon-1	TERN 21

Gets the terrain heights at the corner points of the interpolation rectangle from the terrain height data base array

F1 = th(ilat,ilon)	TERN 23
F2 = th(ilat,ilon+1)	TERN 24
F3 = th(ilat+1,ilon)	TERN 25
F4 = th(ilat+1,ilon+1)	TERN 26

Computes normalized latitude and longitude displacements from the corner of the interpolation rectangle

ylat = 1. + (90.+alat)/dlat - ilat	TERN 28
xlon = 1. + (alon/dlon) - ilon	TERN 30

Does a bi-linear interpolation across the interpolation rectangle to find the terrain height at the desired location

Terr = F1 + (F2 - F1)*xlon + (F3 - F1)*ylat	TERN 32
& + (F4 - F2 - F3 + F1)*xlon*ylat	TERN 33

Finds the normalized distances from the Viking 1 and Viking 2 sites

radvl1 = ((alat-vl1lat)**2 + (alon-vl1lon)**2)/4.0	TERN 35
radvl2 = ((alat-vl2lat)**2 + (alon-vl2lon)**2)/4.0	TERN 36

Modifies the interpolated terrain value so that there is a smooth transition to the Viking site value, if the location is within about 1 degree of lat-lon from either of the Viking sites

If (radvl1 .lt. 1.0)then	TERN 38
Terr = (1.-radvl1)*vl1hgt + Terr*radvl1	TERN 39
Else If(radvl2 .lt. 1.0)then	TERN 40
Terr = (1.-radvl2)*vl2hgt + Terr*radvl2	TERN 41
Endif	TERN 42
Terrain = Terr	TERN 43

**Subroutine:** THERMOS

**Code:** THRM

**Description:** Subroutine for the Stewart thermosphere model. Returns the temperature, pressure, molecular weight, mass density and number density concentrations versus altitude above the base of the thermosphere.

**Called By:** STEWART2

**Common Blocks Used (See Table 2-3 for a list of variables in common blocks):**

None

**Input Variables (not passed through commons):**

Name	Type	Description
ES. . . . .	REAL*4	array of thermospheric variability factors for the input standard deviations for short term (std1) and long term (SIGMA) variability
FLAG. . . . .	REAL*4	test flag, set to 1 to get diagnostic output
IU0 . . . . .	INTEGER*4	unit number for screen output of messages
LAT . . . . .	REAL*4	current latitude
LST . . . . .	REAL*4	local solar time
RF. . . . .	REAL*4	total radius (radius of reference ellipsoid plus height)
TF. . . . .	REAL*4	temperature at base of thermosphere
TINF. . . . .	REAL*4	exospheric temperature
ZF. . . . .	REAL*4	height of base of thermosphere
ZZF . . . . .	REAL*4	current height above height ZF

**Output Variables (not passed through commons):**

Name	Type	Description
MDZ . . . . .	REAL*4	atmospheric constituent mass density
MOLWTG. . . .	REAL*4	molecular weight
NDZ . . . . .	REAL*4	atmospheric constituent number density
PRZ . . . . .	REAL*4	atmospheric constituent partial pressure
TOTALMDZ. . .	REAL*4	total atmospheric mass density
TOTALNDZ. . .	REAL*4	total atmospheric number density
TOTALPRZ. . .	REAL*4	total atmospheric pressure
TZ. . . . .	REAL*4	local temperature at current height

**Local Variables (not passed through commons):**

Name	Type	Description
AO. . . . .	REAL*4	factor in atomic oxygen calculation
BK. . . . .	REAL*4	numerical constant for the number density calculations
DM. . . . .	REAL*4	molecular mass array
FF. . . . .	REAL*4	fractional composition of the heterosphere
FO. . . . .	REAL*4	factor in atomic oxygen calculation
GF. . . . .	REAL*4	acceleration of gravity at height ZF
HH. . . . .	REAL*4	scale heights of the heavy gas constituents
I . . . . .	INTEGER*4	index for heavy gas calculations
J . . . . .	INTEGER*4	index for light gas calculations
K . . . . .	INTEGER*4	dummy index in implied loop for write statement
M . . . . .	REAL*4	molecular weights for the constituent gases
P1BAR . . . .	REAL*4	pressure of 1 bar
PFH . . . . .	REAL*4	partial pressure of H at height ZF
PFH2. . . . .	REAL*4	partial pressure of H2 at height ZF
PFHE. . . . .	REAL*4	partial pressure of He at height ZF
PRESSF. . . .	REAL*4	pressure at height ZF



RADEG . . .	REAL*4	180 / $\pi$
RATIO . . .	REAL*4	factor used in computing partial pressure of H
RREF. . .	REAL*4	local radius of reference ellipsoid
SCALE . . .	REAL*4	scale factor used in temperature calculation
XDM . . .	REAL*4	molecular mass array for light gases
XFF . . .	REAL*4	partial pressure array for He, H <sub>2</sub> and H
XHH . . .	REAL*4	scale heights of the light gas constituents
YSC . . .	REAL*4	scaled height parameter in the temperature calculation

### Methodology:

The Stewart thermosphere model (including the main subroutine STEWART2 and the associated subroutines THERMOS, DZDUST, Escalc, PRSEAS and RELLIPS) was converted to FORTRAN code from the Pascal version listed in Appendix B of "The Mars Atmosphere: Observations and Model Profiles for Mars Missions", David E. Pitts et al., eds., JSC-24455. The model has also been discussed, and given in IDL code, by Ian Stewart, Laboratory for Atmospheric and Space Physics, University of Colorado, Final Report JPL PO # NQ-802429.

Calls RELLIPS to get local radius of reference ellipsoid, RREF, and GF, the acceleration of gravity at the height ZF, the base of the thermosphere

CALL RELLIPS(LAT,RREF,ZF,GF)	THRM 27
------------------------------	---------

Sets the pressure at the base of the thermosphere to 1.26 nanobars ( $1.26 \times 10^{-4}$  N/m<sup>2</sup>)

PRESSF = 1.26E-9	THRM 31
------------------	---------

Sets P1BAR to the pressure of 1 bar ( $1.0 \times 10^5$  N/m<sup>2</sup>)

P1BAR = 1.0E6	THRM 34
---------------	---------

Computes A0 and F0, parameters for use in calculating the atomic oxygen concentration

AO = 0.18 * (1.0 + ES(7))	THRM 36
---------------------------	---------

FO = 0.01 * EXP(ES(4) + ES(5))	THRM 38
--------------------------------	---------

Evaluates SCALE, the scale factor used in the temperature versus height

SCALE = TF / 9.20	THRM 40
-------------------	---------

Sets the molecular weight constant arrays M, DM and XDM (THRM 41 through THRM 76). Sets the array FF, for the composition of the heterosphere (THRM 77 through THRM 89). Adjusts FF(5) for atomic oxygen

FF(5) = FO*(1.0-AO*SIN(15.0*LST/RADEG)*COS(LAT/RADEG))	THRM 90
--	---------

Computes exobase (height ZF) partial pressures for helium (PFHE), molecular hydrogen (PFH2) and atomic hydrogen (PFH) and converts these to partial pressures (XFF array)

PFHE = 3.3E-16 * TINF	THRM 91
-----------------------	---------

PFH2 = 2.4E-15	THRM 93
if (TINF .LE. 330.0) PFH=5.2E-16*TINF*EXP(-TINF/70.0)	THRM 95
if (TINF .GT. 330.0) then	THRM 97
RATIO = 1440.0 / TINF	THRM 98
PFH=5.8E-18*SQRT(TINF)*EXP(RATIO)/(1.0+RATIO)	THRM 99
ENDIF	THRM101
XFF(0) = PFHE / PRESSF	THRM102
XFF(1) = PFH2 / PRESSF	THRM103
XFF(2) = PFH / PRESSF	THRM104

Calculates local atmospheric temperature at current height

YSC = ZZF * RF / (RF + ZZF)	THRM108
TZ = TINF - (TINF - TF) * EXP(-YSC / SCALE)	THRM109

Loops through the heavy gases (I = 0 for CO<sub>2</sub>, 1 for N<sub>2</sub>, 2 for Argon, 3 for O<sub>2</sub>, 4 for CO, and 5 for atomic oxygen), and computes scale height, HH(I), partial pressure, PRZ(I), number density, NDZ(I), mass density, MDZ(I), and accumulates total mass density, TOTALMDZ, total pressure, TOTALPRZ, and pressure-weighted molecular weight, MOLWTG.

DO 200 I = 0, 5	THRM110
HH(I) = BK * TINF / (GF * DM(I)) / 1.0E5	THRM111
PRZ(I) = PRESSF*FF(I)*EXP(-YSC/HH(I)-(SCALE/HH(I))*ALOG(TZ/TF))	THRM113
NDZ(I) = P1BAR * PRZ(I) / (BK * TZ)	THRM114
MDZ(I) = NDZ(I) * DM(I)	THRM116
TOTALMDZ = TOTALMDZ + MDZ(I)	THRM117
TOTALPRZ = TOTALPRZ + PRZ(I)	THRM118
MOLWTG = MOLWTG + PRZ(I) * M(I)	THRM119
200 CONTINUE	THRM120

Loops through the light gases (J = 0 for He, 1 for H<sub>2</sub>, 2 for H), and computes scale height, XHH(J), partial pressure, PRZ(J+6), number density, NDZ(J+6), mass density, MDZ(J+6), and accumulates total mass density, TOTALMDZ, total pressure, TOTALPRZ, and pressure-weighted molecular weight, MOLWTG.

DO 210 J = 0, 2	THRM121
XHH(J) = BK * TINF / (GF * XDM(J)) / 1.0E5	THRM122
PRZ(J+6)=PRESSF*XFF(J)*EXP(-YSC/XHH(J)-(SCALE/XHH(J))*	THRM124
&    ALOG(TZ/TF))	THRM125
NDZ(J+6) = P1BAR * PRZ(J + 6) / (BK * TZ)	THRM126
MDZ(J + 6) = NDZ(J + 6) * XDM(J)	THRM128
TOTALMDZ = TOTALMDZ + MDZ(J + 6)	THRM129
TOTALPRZ = TOTALPRZ + PRZ(J + 6)	THRM130
MOLWTG = MOLWTG + PRZ(J + 6) * M(J + 6)	THRM131
210 CONTINUE	THRM132

Divides by total pressure to get true total molecular weight, and computes total number density, TOTALNDZ

MOLWTG = MOLWTG / TOTALPRZ	THRM133
TOTALNDZ = P1BAR * TOTALPRZ / (BK * TZ)	THRM134

**Subroutine:** Temps

**Code:** TMPS

**Description:** Computes array of atmospheric temperatures at the significant levels for a given latitude and longitude. Dust effects are included.

**Called By:** ATMOS2

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

None

**Input Variables** (not passed through commons):

Name	Type	Description
ALAT. . . .	REAL*4	local site latitude
ALS . . . .	REAL*4	areocentric longitude of the sun (Ls)
DLON. . . .	REAL*4	site-sun West longitude difference
DUSTA . . .	REAL*4	magnitude of dust storm effect on daily amplitude
DUSTM . . .	REAL*4	magnitude of dust storm effect on daily average
GAM . . . .	REAL*4	lapse rates (-dT/dz) between significant levels
T0BAR . . .	REAL*4	average surface temperature with no dust storm effect
TSURF . . .	REAL*4	local surface temperature, including dust effect

**Output Variables** (not passed through commons):

Name	Type	Description
T . . . . .	REAL*4	array of air temperatures at the significant levels
GAM . . . .	REAL*4	lapse rates, modified by dust storm effects

**Local Variables** (not passed through commons):

Name	Type	Description
A25 . . . .	REAL*4	coefficient array in calculation of T25
ABSLAT. . .	REAL*4	absolute value of latitude
AFACT . . .	REAL*4	factor array for diurnal temperature variation
ALATP . . .	REAL*4	90 minus absolute latitude
ALONMAX . .	REAL*4	longitude where maximum phase occurs
AT25. . . .	REAL*4	latitude dependent coefficient in T25 calculation
B25 . . . .	REAL*4	coefficient array in calculation of T25
BT25. . . .	REAL*4	latitude dependent coefficient in T25 calculation
C25 . . . .	REAL*4	coefficient array in calculation of T25
COSLAT. . .	REAL*4	cosine latitude term in T25 calculation
CT25. . . .	REAL*4	latitude dependent coefficient in T25 calculation
DFACTOR . .	REAL*4	factor array for dust storm effect on diurnal amplitude
DT25. . . .	REAL*4	difference between T25 and value from lapse rates
DTR26 . . .	REAL*4	diurnal amplitude factor for 26 km
DTR30 . . .	REAL*4	diurnal amplitude factor for 30 km
DZ. . . . .	REAL*4	array of height differences between significant levels
FACTOR. . .	REAL*4	height scaling factors for diurnal amplitude (relative to amplitude at 30 km) in non-dust storm conditions
I . . . . .	INTEGER*4	array index
PI120 . . .	REAL*4	$\pi / 120$
PI180 . . .	REAL*4	$\pi / 180$
SINLAT. . .	REAL*4	sine latitude term in T25 calculation
T25 . . . .	REAL*4	air temperature at 25 km
THOUR . . .	REAL*4	phase hour of maximum diurnal perturbation
THOUR0. . .	REAL*4	phase hour for maximum diurnal perturbation at surface
THOUR26 . .	REAL*4	phase hour for maximum at 26 km height
Z . . . . .	REAL*4	height array for significant levels

## Methodology:

Starts by computing an estimate of the temperature at 25 km, T25, from a set of coefficients for latitude and Ls dependence

```
AT25 = A25(0)                                TMPS 41
BT25 = B25(0)                                TMPS 42
CT25 = C25(0)                                TMPS 43
Do 5 i = 1,5,2                                TMPS 44
  sinlat = sin(pi120*(i+1.)*alat/2.)          TMPS 45
  coslat = cos(pi120*(i+1.)*alat/2.)          TMPS 46
  AT25 = AT25 + A25(i)*sinlat                 TMPS 47
  AT25 = AT25 + A25(i+1)*coslat               TMPS 48
  BT25 = BT25 + B25(i)*sinlat                 TMPS 49
  BT25 = BT25 + B25(i+1)*coslat              TMPS 50
  CT25 = CT25 + C25(i)*sinlat                 TMPS 51
5 CT25 = CT25 + C25(i+1)*coslat               TMPS 52
T25 = AT25 + BT25*sin(pi180*als) + CT25*cos(pi180*als) TMPS 53
```

Computes the daily average atmospheric temperature (no dust storm correction) at each of the significant levels, from the daily average surface temperature and the lapse rates between the significant levels

```
T(0) = T0bar                                TMPS 56
Do 10 i = 1,3                                TMPS 57
10 T(i) = T(i-1) - gam(i)*dz(i)              TMPS 58
```

Finds the difference from the temperature estimate T25 and the temperature at 25 km, computed from the lapse rates

```
DT25 = T25 - (T(2) + 2.*T(3))/3.            TMPS 60
```

Adjusts the temperature and lapse rates for the first three significant levels, based on the value of T25

```
Do 15 i = 1,3                                TMPS 62
  T(i) = T(i) + z(i)*DT25/25.                 TMPS 63
15 gam(i) = (T(i-1) - T(i))/dz(i)             TMPS 64
```

Adjusts the temperatures at the 4th and 5th significant levels, based on the new value of T(3)

```
Do 20 i = 4,5                                TMPS 66
20 T(i) = T(i-1) - gam(i)*dz(i)               TMPS 67
```

Compute non-dust storm effects if dustM = 0 (TMPS 70 - TMPS 81). Calculates factor = afact, the latitude dependence factor for the diurnal temperature variation at 5 km height

```
If (dustM .eq. 0)then                        TMPS 70
  If (abslat .le. 25)then                    TMPS 72
    Factor(1) = 0.79                        TMPS 73
  Else If (abslat .ge. 45)then               TMPS 74
    Factor(1) = 0.43                        TMPS 75
```

Else	TMPS 76
Factor(1) = 1.24 - 0.018*abslat	TMPS 77
Endif	TMPS 78
Do 25 i = 1,5	TMPS 79
25 afact(i) = factor(i)	TMPS 80
Endif	TMPS 81

Computes the relative temperature amplitude at 30 km height

dtr30 = 0.0141*(90. - abslat)**0.2	TMPS 84
------------------------------------	---------

Evaluates thour26, the phase hour for maximum temperature at 26 km height

If (alat .le. -70.)then	TMPS 89
thour26 = 21.	TMPS 90
Else If (alat .ge. -20.)then	TMPS 91
thour26 = 11.5	TMPS 92
Else	TMPS 93
thour26 = 7.7 - 0.19*alat	TMPS 94
Endif	TMPS 95

Computes the effects of a dust storm on the daily average temperature and on the diurnal temperature variation, if a dust storm is in progress (TMPS 96 - TMPS123).

If (dustM .gt. 0.0)then	TMPS 96
C... Adjust hour of diurnal temperature maximum at 26 km	TMPS 98
thour26 = (1. - dustA)*thour26 + dustA*16.7	TMPS 99
C... Adjust height factors for diurnal amplitudes	TMPS100
Do 30 i = 1,5	TMPS101
30 afact(i) = (1. - dustA)*factor(i) + dustA*dfactor(i)	TMPS102

Adjustments for dust storm effects on the daily average temperature for latitudes less than 50 degrees (absolute value) are done in TMPS104 through TMPS110. For absolute latitude greater than 50 degrees, the adjustments are done in TMPS111 through 120.

If (abslat .le. 50.)then	TMPS104
dtr26 = 0.0465 + 1.90E-6*abslat**2	TMPS105
T(1) = T(1) + 13.*dustM	TMPS106
T(2) = T(2) + 36.*dustM	TMPS107
T(3) = T(3) + (48. + 0.0024*abslat**2)*dustM	TMPS108
T(4) = T(4) + 30.*dustM	TMPS109
T(5) = T(5) + 26.*dustM	TMPS110
Else	TMPS111
alatp = 90. - abslat	TMPS112
dtr26 = ((1.597E-6*alatp - 1.417E-4)*alatp +	TMPS113
& 4.394E-3)*alatp	TMPS114
T(1) = T(1) + (28. - 0.3*abslat)*dustM	TMPS115
T(2) = T(2) + (11. + 0.015625*alatp**2)*dustM	TMPS116
T(3) = T(3) + (25. + 0.018125*alatp**2)*dustM	TMPS117
T(4) = T(4) + (50. - 0.4*abslat)*dustM	TMPS118
T(5) = T(5) + (46. - 0.4*abslat)*dustM	TMPS119
Endif	TMPS120

Adjusts the diurnal amplitude from 26 to 30 km

```

    dtr30 = (1. - dustA)*dtr30 + dustA*1.072*dtr26
Endif

```

TMPS122  
TMPS123

Steps through heights of the significant levels and evaluates the temperatures, T(i), including dust storm effects and diurnal variations

```

    Do 40 i = 1,5
C...   Compute diurnal adjustment to average temperatures.
C...   Interpolate (extrapolate) for phase hour of maximum diurnal
C       perturbation
        thour = thour0 + (thour26 - thour0)*z(i)/26.
C...   Make sure phase hour is in range 0 < thour < 24
        If (thour .gt. 24.)thour = thour - 24.
        If (thour .lt. 0.)thour = thour + 24.
C...   Longitude where maximum phase occurs
        alonmax = 15.*(thour - 12.)
C...   Evaluate temperature including diurnal perturbation
        T(i) = T(i)*(1. + dtr30*afact(i)*cos(pi180*(dlon + alonmax)))
    40 Continue
        T(0) = Tsurf

```

TMPS125  
TMPS126  
TMPS127  
TMPS128  
TMPS129  
TMPS130  
TMPS131  
TMPS132  
TMPS133  
TMPS134  
TMPS135  
TMPS136  
TMPS137  
TMPS138

Re-evaluates the lapse rates (K/km), based on the new values of temperatures at the significant levels

```

    Do 50 i = 1,5
50 gam(i) = (T(i-1) - T(i))/dz(i)

```

TMPS140  
TMPS141

**Subroutine:** Tsurface

**Code:** TSRF

**Description:** Computes surface temperature for a given latitude and longitude, areocentric longitude of the sun (Ls) and orbital radius. Also computes the diurnal average surface temperature, with and without dust storm effects.

**Called By:** ATMOS2

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

None

**Input Variables** (not passed through commons):

Name	Type	Description
ALS. . . .	REAL*4	areocentric longitude of the sun (Ls)
AU. . . .	REAL*4	orbital radius of Mars from Sun (in astronomical units)
DUSTT . . .	REAL*4	relative dust storm effect (0-1)
SITLA . . .	REAL*4	current latitude
SITLO . . .	REAL*4	current longitude
SUNLA . . .	REAL*4	latitude of sub-solar point on surface
SUNLO . . .	REAL*4	West longitude of sub-solar point on surface

**Output Variables** (not passed through commons):

Name	Type	Description
TOBAR . . .	REAL*4	daily average surface temperature without dust effects
TAVG. . . .	REAL*4	daily average surface temperature including dust effect
TMAX. . . .	REAL*4	daily maximum surface temperature
TMIN. . . .	REAL*4	daily minimum surface temperature
TSURF . . .	REAL*4	local surface temperature at current position and time

**Local Variables** (not passed through commons):

Name	Type	Description
ABSLAT. . .	REAL*4	absolute value of latitude
ABSORB. . .	REAL*4	daily total solar radiation absorbed at surface
ALBEDO. . .	REAL*4	surface reflectance for solar radiation
ATRANS. . .	REAL*4	factor used to compute average solar transmittance
AVCOS . . .	REAL*4	daily average value of the cosine of the solar zenith angle at the site latitude
AVMU. . . .	REAL*4	cosine of the solar zenith angle at solar noon
CAPNORTH. .	REAL*4	boundary of the north polar cap
CAPSOUTH. .	REAL*4	boundary of the south polar cap
CLAT. . . .	REAL*4	cosine of the current latitude
CLATS . . .	REAL*4	cosine of the solar latitude
COSDLON . .	REAL*4	cosine of the hour-angle length of the solar day
CRLAT . . .	REAL*4	latitude of the boundary at which the daily total amount of solar radiation is 0 (total darkness for the day)
DELTA . . .	REAL*4	optical depth for a vertical path through the atmosphere
DLO . . . .	REAL*4	longitude difference from sun to site (also equal to the solar hour angle in degrees, measured from solar noon)
DLON. . . .	REAL*4	hour angle length of the solar day at the site position
DTR . . . .	REAL*4	$\pi / 180$
F0. . . . .	REAL*4	the solar constant at current Mars orbital radius
PI. . . . .	REAL*4	$\pi$
PMMU. . . .	REAL*4	minimum value of the cosine of the solar zenith angle

POLAR . . .	REAL*4	factor for temperature correction in the polar cap zone
QA. . . . .	REAL*4	amplitude of the daily variation in solar heating at the surface (difference between average and minimum solar heating)
SINDLON . .	REAL*4	sine of the hour-angle length of the solar day
SITELAT . .	REAL*4	current latitude in radians
SLAT. . . .	REAL*4	sine of current latitude
SLATS . . .	REAL*4	sine of the solar latitude
SSALB . . .	REAL*4	single scatter albedo for atmospheric scattering
SUNLAT. . .	REAL*4	solar latitude in radians
TAMP. . . .	REAL*4	amplitude of the diurnal surface temperature variation
TAUBAR. . .	REAL*4	daily average of the solar transmittance to the surface
TLAT. . . .	REAL*4	tangent of the current latitude
TLATS . . .	REAL*4	tangent of the solar latitude

### Methodology:

Computes cosine of the hour-angle length of the solar day at the site latitude

```
cosdlon = -tlat*tlats
```

TSRF 28

Calculates crlat, the latitude at which daily insolation = 0, dlon, the length of the solar day, and polar, the temperature adjustment factor in the polar cap regions at locations where the daily insolation is zero. If |cosdlon| > 1 then either the insolation lasts all day (sun never sets, dlon =  $\pi$  radians) or there is no daylight (sun never rises, dlon = 0).

```

If (Abs(cosdlon) .gt. 1.)then
  If(sitla*sunla.lt.0.)Then
    If (sunla.gt.0.0)Then
      crlat = sunla - 90.
    Else
      crlat = sunla + 90.
    Endif
    polar = (abs(sitla-crlat))/25.19
    dlon = 0.
  Else
    dlon = pi
  Endif
  sindlon = 0.
Else
  sindlon = sqrt(1. - cosdlon**2)
  dlon = pi/2.
  If(cosdlon.ne.0.)dlon = atan(sindlon/cosdlon)
  If (dlon .le. 0.0)dlon = pi + dlon
Endif

```

TSRF 32  
 TSRF 32a  
 TSRF 33a  
 TSRF 33b  
 TSRF 33c  
 TSRF 33d  
 TSRF 33e  
 TSRF 35  
 TSRF 36  
 TSRF 37  
 TSRF 38  
 TSRF 39  
 TSRF 40  
 TSRF 44  
 TSRF 45  
 TSRF 46  
 TSRF 47  
 TSRF 48  
 TSRF 48a

Computes avcos, the daily average of the cosine of the solar zenith angle at the site latitude

```

avcos = (slats*slat*dlon + clats*clat*sindlon)/pi
If (avcos .lt. 0.0)avcos = 0.

```

TSRF 50  
 TSRF 51



Sets delta, the dust optical depth and ssalb, the single-scatter albedo to model values, and computes avmu, the cosine of the solar zenith angle at solar noon.

```

delta = 0.3
ssalb = 0.85
atrans = ssalb/2.
avmu = slat*slats + clat*clats

```

TSRF 51b  
TSRF 51c  
TSRF 51d  
TSRF 51f

Computes taubar, the daily-average solar transmittance

```

If (avmu.le.0.0)Then
    avmu = 0.0
    taubar = 0.0
Else
    taubar = atrans + (1. - atrans)*exp(-delta*(1./avmu))
Endif

```

TSRF 51h  
TSRF 51i  
TSRF 51j  
TSRF 51k  
TSRF 51l  
TSRF 51m

Uses the Alb function to get the surface albedo

```

albedo = Alb(als,sitla)

```

TSRF 51o

Calculates the daily total amount of solar radiation absorbed at the surface

```

Absorb = taubar*(1. - albedo)*F0*avcos

```

TSRF 53

Finds pmmu, the cosine of the minimum of the solar zenith angle

```

pmmu = slat*slats - clat*clats
If (pmmu.lt.0.0)pmmu = 0.0

```

TSRF 53b  
TSRF 53c

Evaluates Qa, the amplitude of the diurnal surface heating

```

Qa = taubar*(1. - albedo)*F0*(avmu - pmmu)/2.

```

TSRF 53e

Determines the limits of the northern and southern polar caps

```

capnorth = 90. - polecap(90.,als)
capsouth = -90. + polecap(-90.,als)

```

TSRF 53g  
TSRF 53h

Computes the daily average surface temperature, including the polar correction if in the polar cap region

```

If (sitla.gt.capnorth.or.sitla.lt.capsouth)Then
    Tav = 140.5 + 0.2336*Absorb - 8.5*polar
Else
    Tav = 140.5 + 0.8221*Absorb - 0.001425*(Absorb**2)
Endif

```

TSRF 53j  
TSRF 53k  
TSRF 53l  
TSRF 53m  
TSRF 53n

Calculates Tamp, the amplitude of the daily surface temperature variation

Tamp = 0.16\*Qa

TSRF 53p

Finds the minimum and maximum daily temperatures at site latitude

Tmax = Tavg + Tamp

TSRF 55

Tmin = Tavg - Tamp

TSRF 56

Saves the daily average surface temperature, without dust storm effect, as T0bar

T0bar = Tavg

TSRF 59

Compute the effects of a dust storm (if any) on Tavg, Tmax and Tmin

If (dustT .gt. 0.0) then

TSRF 61

abslat = abs(sitla)

TSRF 62

If (abslat .le. 50.) then

TSRF 63

Tavg = Tavg - (7. - 1.28E-6\*abslat\*\*4)\*dustT

TSRF 64

Else

TSRF 65

Tavg = Tavg + (7.5 - 0.13\*abslat)\*dustT

TSRF 66

Endif

TSRF 67

Tamp = (0.5 - 0.25\*dustT)\*(Tmax - Tmin)/T0bar

TSRF 68

Tmax = Tavg\*(1. + Tamp)

TSRF 69

Tmin = Tavg\*(1. - Tamp)

TSRF 70

Endif

TSRF 71

Finds the longitude difference from sun to site (equal solar hour angle, in degrees, measured from solar noon), and evaluates the local surface temperature from the minimum and maximum daily values

dlo = sunlo - sitlo

TSRF 74

if (dlo .gt. 180.) dlo = dlo - 360.

TSRF 75

if (dlo .lt. -180.) dlo = dlo + 360.

TSRF 76

Tsurf = Tdiurnal(dlo, Tmin, Tmax)

TSRF 77

**Subroutine:** Wavepert

**Code:** WAVE

**Description:** Zurek wave perturbations at given height, latitude and local time. Includes dust storm effects. Computes density perturbations from the original Zurek temperature wave perturbation.

**Called By:** Datastep

**Common Blocks Used** (See Table 2-3 for a list of variables in common blocks):

WAVEDAT

**Input Variables (not passed through commons):**

Name	Type	Description
CHGT. . . .	REAL*4	current height (km)
CLAT. . . .	REAL*4	current latitude (degrees)
DUSTA . . .	REAL*4	relative magnitude of dust storm effect on phase (0-1)
DUSTM . . .	REAL*4	relative magnitude of dust storm effect on amplitude (0-1)
TLOCAL. . .	REAL*4	local time in Mars hours (1/24th Sols)

**Output Variables (not passed through commons):**

Name	Type	Description
AMP1. . . .	REAL*4	diurnal amplitude of wave (% of mean)
AMP2. . . .	REAL*4	semi-diurnal amplitude of wave (% of mean)
WAVE. . . .	REAL*4	relative density perturbation of wave (% of mean)

**Local Variables (not passed through commons):**

Name	Type	Description
AMPC1 . . .	REAL*4	clear-atmosphere diurnal amplitude (% of mean)
AMPD1 . . .	REAL*4	dusty-atmosphere diurnal amplitude (% of mean)
AMPD2 . . .	REAL*4	dusty-atmosphere semi-diurnal amplitude (% of mean)
AMPI1 . . .	REAL*4	intermediate amplitude variable used in calculations
AMPI2 . . .	REAL*4	intermediate amplitude variable used in calculations
DLAT. . . .	REAL*4	relative latitude displacement from interpolation point
DZ. . . . .	REAL*4	intermediate value of relative height displacement
DZA . . . .	REAL*4	relative height displacement from interpolation point
H . . . . .	REAL*4	height scale for vertical interpolation
I1. . . . .	INTEGER*4	1st height index for interpolation
I2. . . . .	INTEGER*4	2nd height index for interpolation
OMEGA1. . .	REAL*4	diurnal frequency (15 ° / Mars hour)
OMT1. . . .	REAL*4	phase-adjusted diurnal frequency
OMT2. . . .	REAL*4	phase-adjusted semi-diurnal frequency
PH1 . . . .	REAL*4	diurnal phase (hours)
PH2 . . . .	REAL*4	semi-diurnal phase (hours)
PHC1. . . .	REAL*4	clear-atmosphere diurnal phase (hours)
PHD1. . . .	REAL*4	dusty-atmosphere diurnal phase (hours)
PHD2. . . .	REAL*4	dusty-atmosphere semi-diurnal phase (hours)
PHI1. . . .	REAL*4	intermediate phase variable used in calculations
PHI2. . . .	REAL*4	intermediate phase variable used in calculations
Z1. . . . .	REAL*4	lower height for vertical interpolation
Z2. . . . .	REAL*4	upper height for vertical interpolation

**Methodology:**

The Zurek wave perturbation model was adapted from Section 4.3 of "The Mars Atmosphere: Observations and Model Profiles for Mars Missions", Report No. JSC-24455, David E. Pitts et al., eds., and the draft report by Pitts, Tillman, Pollack and Zurek, "Model Profiles of the Mars Atmosphere for the Mars Rover and Sample Return Mission", draft report, March 11, 1988.

Computes diurnal frequency (15 ° / Mars hour)

omega1 = Atan(1.)/3.

WAVE 13

Evaluate i1 and i2, the array index values for height interpolation, the corresponding altitudes, z1 and z2, and dza, the relative height displacement between z1 and z2

H = 11.26  
i1 = 1 + Int(2.\*CHGT/H)  
If (i1 .lt. 1)i1 = 1  
If (i1 .gt. 11)i1 = 11  
i2 = i1 + 1  
z1 = H\*(i1 - 1.)/2.  
z2 = H\*i1/2.  
dz = 2.\*(CHGT - z1)/H  
dza = dz  
If (dz .gt. 1.)dza = 1.

WAVE 14  
WAVE 15  
WAVE 16  
WAVE 17  
WAVE 18  
WAVE 19  
WAVE 20  
WAVE 21  
WAVE 22  
WAVE 23

Uses the amplitude interpolation function (ampint) to interpolate on latitude (in the absolute latitude ranges 0-20°, 20-45° or > 45°). Uses the phase interpolation function (phasint) to interpolate the phase. Also uses ampint and phasint to do height interpolation. In the interpolation section (WAVE 24 - WAVE 77), the amplitude variables are designated "amp" and the phase variables are designated "ph", "c" denotes clear-atmosphere and "d" denotes dusty-atmosphere, 100, 120 and 145 denote diurnal variables at latitudes 0, 20 and 45°, respectively; and 200, 220 and 245 denote semi-diurnal variables at the same respective latitudes.

Use the ampint function to interpolate between clear and dusty diurnal amplitudes, based on the value of DustM, the dust magnitude effect. Also adjust the semi-diurnal amplitude (applicable only to the dusty case).

amp1 = ampint(ampc1,ampd1,DustM)/100.  
amp2 = DustM\*ampd2/100.

WAVE 79  
WAVE 80

Use the phasint function to interpolate between clear and dusty diurnal phases, based on the value of DustA, the magnitude of the dust effect on phase.

ph1 = phasint(phc1,phd2,DustA,omega1)

WAVE 81

Compute the phase-adjusted frequencies for the diurnal and semi-diurnal components, and evaluate the density wave perturbation from the temperature wave model values [see equations (1) through (4) in the section "The Zurek Wave Perturbation Model" of the Release 2 Technical Report, 1993; see Appendix C].

omt1 = omega1\*(TLOCAL - ph1)  
omt2 = 2.\*omega1\*(TLOCAL - ph2)  
wave = amp1\*(sin(omt1) - cos(omt1)) + amp2\*(sin(omt2) -  
& cos(omt2))

WAVE 83  
WAVE 84  
WAVE 85  
WAVE 86

## **APPENDIX B**

### **MARS-GRAM RELEASE #1 TECHNICAL REPORT**

This Appendix contains the technical portions of the Release #1 Report for Mars-GRAM (version 2.21), "The Mars Global Reference Atmospheric Model (Mars-GRAM)", Dale L. Johnson and Bonnie F. James (Grant Monitors), C. G. Justus and George Chimonas, October 8, 1989, prepared under Georgia Tech grant No. NAG8-078, for NASA Marshall Space Flight Center. Appendix material (giving outdated information on program input, output and running characteristics) has been deleted.

## **ABSTRACT**

An engineering model atmosphere for Mars has been developed with many of the same features and capabilities of the highly successful Global Reference Atmospheric Model (GRAM) program for Earth's atmosphere, including mean values for density, temperature, pressure, and wind components, and density perturbation magnitudes and random perturbation profiles for density variations along specified trajectories. In the lower atmosphere of Mars (up to 75 km) the model is built around parameterizations of height, latitudinal, longitudinal and seasonal variations of temperature determined from a survey of published measurements from the Mariner and Viking programs. Pressure and density are inferred from the temperature by making use of the hydrostatic and perfect gas law relationships. For the upper atmosphere (above about 120 km), the thermospheric model of Stewart (1987) is used. A hydrostatic interpolation routine is used to insure a smooth transition from the lower portion of the model to the Stewart thermospheric model. Mars-GRAM includes parameterizations to simulate the effects of seasonal variation, diurnal variation, dust storm effects, effects due to the orbital position of Mars, effects of the large seasonal variation in surface atmospheric pressure because of differential condensation/ sublimation of the CO<sub>2</sub> atmosphere in the polar caps, and effects of Martian atmospheric mountain wave perturbations on the magnitude of the expected density perturbations. The thermospheric model includes a parameterization for the effects of solar activity, measured by the 10.7 cm solar radio flux. Winds are computed by an aereostrophic (thermal wind) approximation, with the inclusion of the effects of molecular viscosity, which, because of the low atmospheric densities, can be very important at high altitudes. The mountain wave perturbation model also includes a new damping approximation due to the effects of molecular viscosity.

## INTRODUCTION AND BACKGROUND

A highly successful and well-utilized engineering model for the Earth's atmosphere, the Global Reference Atmospheric Model (GRAM), was developed at Georgia Tech (Justus, et al., 1975, 1976), and has undergone several improvement cycles (Justus and Roper 1987; Justus, 1988). GRAM applications include orbital mechanics and lifetime studies, vehicle design and performance criteria, attitude control analysis problems, analysis of effects of short-term density variation from geomagnetic storms, and aerobraking analyses (for missions requiring return from geosynchronous orbit to space-station rendezvous).

In addition to evaluating the mean density, temperature, pressure, and wind components at any height, latitude, longitude and monthly period, GRAM also allows for the simulation of "random perturbation" profiles about the mean conditions. This feature permits the simulation of a large number of realistic density profile realizations along the same trajectory through the atmosphere, with realistic values of scales of variation and peak perturbation values (e.g., the random perturbation profiles produce values which exceed the +3 standard deviation value approximately 1% of the time).

With the planning activity for upcoming and proposed unmanned missions to Mars (e.g. Mars Observer, Mars Aeronomy Observer, Mars Rover and Sample Return), as precursors to a possible future manned mission, interest has developed in having a similar type of engineering-oriented atmospheric model as GRAM for the atmosphere of Mars. This report discusses the development of such a new model, the Mars Global Reference Atmospheric Model (Mars-GRAM). The Mars-GRAM program has been developed as a reference model atmosphere for such engineering applications as aerobraking or aerocapture within the atmosphere of Mars (which requires knowledge of Martian atmospheric density to altitudes as low as 20 km), orbiter operations at Mars (requiring atmospheric density information at orbital altitudes), Mars Lander entry and exit operations (requiring atmospheric density and wind estimates from the surface to orbital altitudes), Lander/Rover operational environment on the Mars surface (requiring atmospheric thermal, wind and solar radiation environments at the surface of Mars), and environments for design and planning of balloon measurement systems, such as being considered on the Soviet Mars 1994 Mission (requiring atmospheric thermal, wind and solar radiation environments within the planetary boundary layer of Mars).

This report outlines the observational and modeling basis behind the development of the Mars-GRAM program, provides documentation on the operations of the Mars-GRAM program (available in FORTRAN-77 on IBM-PC compatible 360k diskettes), and presents some example applications for the Mars-GRAM model. The report also suggests some areas for possible improvements for the current Mars-GRAM program, such as the incorporation of routines for the quantitative estimation of solar radiation at the surface of Mars, more realistic treatment of diurnal and latitudinal variations of density, temperature and wind at thermospheric altitudes, and the overall improvement of atmospheric parameterizations by further analysis of the archived data bases for the atmosphere of Mars.

## THE MARS GLOBAL REFERENCE ATMOSPHERIC MODEL (MARS-GRAM)

Mars-GRAM, is based on parameterizations to approximate, as realistically as possible, the temperature, pressure, density and winds of the Martian atmosphere, and their latitudinal, longitudinal, diurnal, seasonal and altitude variation, from the surface through thermospheric altitudes. Parameterizations are also included for the effects of global-scale dust storms on the variations of the thermodynamic and wind properties of the Martian atmosphere. Recently, David Kaplan, compiler of the definitive report "Environment of Mars, 1988" (Kaplan, 1988), has decided to propose Mars-GRAM as the reference model atmosphere for use by engineers on upcoming equipment design contracts for NASA's Mars Rover and Sample Return Mission (Kaplan, private communication).

The near-surface air temperature on Mars is parameterized in the Mars-GRAM program by computing an approximate value for the geographically and seasonally-dependent daily total absorbed radiation flux. The daily average, maximum and minimum near-surface air temperatures are then calculated from a simple regression relationship assumed between the daily absorbed flux and the temperature parameters. The absorbed flux estimates include the variations in insolation due to the orbital position of Mars, the latitudinal variation of surface albedo (Pollack, et al. 1981), and seasonally-dependent parameterizations for the polar caps (Martin and James, 1986a, 1986b; Iwasaki, 1986; Paige and Ingersoll, 1985; Philip, 1986) and polar hood clouds (James et al., 1987).

The resultant seasonally and latitudinally-dependent daily average, maximum and minimum temperatures from the Mars-GRAM model are shown in Figures 1-3. These agree well with the surface temperature maps of Kieffer et al. (1977), with more realistic variations in the polar regions, as suggested by the observations of Kieffer (1979). Seasonal variations of the daily maximum, minimum and average temperature at the latitudes of the Viking 1 and Viking 2 landers, as evaluated by Mars-GRAM, are shown in Figures 4a and 5a. These plots agree nicely with the Viking 1 and Viking 2 observational data reported by Ryan and Henry (1979), shown for comparison in Figures 4b and 5b.

Parameterizations for the seasonal, latitudinal, diurnal and dust-storm influence on surface pressure were taken from data of Hess et al. (1976, 1977, and 1980), Leovy (1979), Leovy and Zurek (1979), Leovy (1981) and Tillman (1988). Model information on the latitudinal variations of surface pressure was incorporated from Haberle et al. (1982). Figure 6a presents the Mars-GRAM simulations for daily average surface pressure versus time at the Viking 1 and Viking 2 Lander sites. These compare favorably with observations of Hess et al. (1980) and Tillman (1988), as shown in Figure 5b (as presented by Kaplan, 1988). Parameterizations for the seasonal, latitudinal, and diurnal variation of pressure on the reference ellipsoid level were developed from the Viking 1 and Viking 2 data and the model of Haberle et al. (1982). Pressures are adjusted from the values on the reference ellipsoid to values at the local effects of dust storms on daily mean pressure and on the amplitude of the diurnal variation in pressure are evident in Figure 6b. The dust-storm effects on daily average pressure are assumed to be due to perturbations in the meridional circulation strength of the Martian Hadley cell (Haberle et al., 1982), and are therefore taken to have perturbation magnitudes which are antisymmetric in latitude. Thus, when a dust storm causes increased daily average surface pressure at northern latitudes, it is assumed to cause a comparable decrease in daily average surface pressure at the corresponding southern latitude. For lack of any other information, the effects of dust storms on the magnitude of the diurnal variation are assumed to be symmetric in latitude (i.e. equal in magnitude and sign at comparable northern and southern latitudes).



Mars-GRAM parameterizations for the geographical, seasonal and altitude dependence on non-dust storm, daily average temperatures above the surface come from a combination of observational and model values. The observational data include: Mariner 9 IRIS data from Conrath (1981), and Conrath data as reported by Leovy (1982) and Magalhaes (1987), Viking IRTM data (Martin et al., 1982), Mariner 9 radio occultation data from Kliore et al. (1983), and Viking 1 radio occultation data (Fjeldbo et al., 1977), Lindal et al. (1979), and Davies (1979). Model output used include results from Pollack et al. (1981), Haberle et al. (1982), and Pitts et al. (1988).

The parameterizations in Mars-GRAM for temperature variations during dust storm conditions were taken from observational data of Kliore et al. (1972), Jakosky and Martin (1987), Martin et al. (1982), Hanel et al. (1972), and Conrath (1975). Model values for dust storm effects were taken from Haberle et al. (1982) and Pitts et al. (1988).

Data for the Mars-GRAM parameterizations of the height variation of the diurnal (longitudinal) variations of temperature about the daily mean value were taken from Viking IRTM observations of Martin et al. (1982), Mariner 9 IR spectroscopy data of Hanel et al. (1972), and model results from Zurek, as reported in Pitts et al. (1988). Diurnal temperature variations are significantly larger during dust storm periods than during non-dust storm conditions.

Examples of the altitude dependence of temperature and density during non-dust storm conditions are provided by Figures 7 and 8, which compare Mars-GRAM simulations for the date, time and location of the Viking 1 Lander site with temperature observations from the Viking Lander 1 entry profile (Seiff and Kirk, 1977) and the COSPAR Northern Hemisphere Summer Mean density profile (Seiff, 1982). Mars-GRAM simulations of the height and latitudinal variation of daily average temperatures are shown in Figure 9, for Northern Hemisphere spring equinox (areocentric longitude of sun,  $L_s = 0^\circ$ ), in Figure 10 for Northern Hemisphere summer solstice ( $L_s = 90^\circ$ ), and in Figure 11 for Northern Hemisphere winter solstice ( $L_s = 270^\circ$ ). Examples of Mars-GRAM simulations of dust storm effects on surface temperature are shown in Figures 4a and 5a. An example of a Mars-GRAM dust-storm height-latitude temperature cross section (at  $L_s = 270^\circ$ ) is shown in Figure 12.

In Figures 13 and 14 the model height-latitude cross sections of temperature and zonal wind are compared for Mars-GRAM simulation results for  $L_s = 49^\circ$  and for Mariner 9 results from  $L_s = 43$ - $54^\circ$  (Leovy, 1982, from data provided by Conrath). For the same conditions as in Figure 13, Figure 15 shows Mars-GRAM simulations of height-latitude cross sections of pressure ( $\text{N/m}^2$ , log-base-10 scale) and of density ( $\text{kg/m}^3$ , log-base-10 scale). Figure 15a illustrates the fact that the conversion between height and pressure is not constant with latitude at a given seasonal time.

The perturbations in pressure and density evident between about  $30^\circ\text{S}$  and  $60^\circ\text{S}$  in Figure 15 are due to the influence of terrain height on surface pressure. The cross sections of Figure 15 were evaluated along the zero longitude meridian. Terrain height contours used in Mars-GRAM, shown in Figure 16, indicate that surface altitudes reach more than 3 km above the reference ellipsoid over the latitude range  $30$ - $60^\circ\text{S}$ . The reference ellipsoid in Mars-GRAM is defined by the equatorial and polar radii as given by Cain et al. (1973).

Examples of the Mars-GRAM capabilities to simulate the spatial and temporal variation of global dust storm effects on temperature are provided by Figures 17 and 18. These figures show both daily average temperatures and the range of diurnal variation in temperature during the development (Figure 17) and decay (Figure 18) of global dust storms. Figure 17, similar in format to Figure 5 of Martin et al. (1982), shows the simulated development of dust storm effects on temperature at 30 km altitude for a simulation of the 1977b global dust storm, which was observed by Viking IRTM. The

simulations in Figure 17 were based on an assumed intensity of 3.0 (the maximum possible in Mars-GRAM). Comparison with the data of Martin et al. indicates that better correspondence would be achieved by attributing an intensity of about 2.0 to the 1977b storm. Figure 18, similar in format to Figure 1 of Conrath (1975), is for a simulation of the decay of the 1971b global dust storm, which was observed by Mariner 9. The simulation in Figure 18 also assumed an intensity of 3, although the model would compare better with the 1971b storm observations if an intensity of about 2 were assumed.

The newly-developed parameterizations for Mars-GRAM provide a simulation capability to altitudes reaching the base of the thermosphere. For simulations of the seasonal, geographical and solar-activity dependence of thermospheric conditions, the Mars-GRAM uses an adaptation of the thermospheric model of Stewart (Culp and Stewart, 1983, 1984; Stewart and Hanson, 1982; Stewart, 1987; see also the revised Stewart program code given in Pitts et al., 1977).

The Stewart model thermosphere incorporates results from a number of data and model sources, e.g. the Mars Reference Atmosphere (Kliore, 1982), occultation data and mass spectrometer data from Mariner and from Viking orbiters (Fjeldbo et al., 1966, 1970, 1977; Kliore et al., 1972; Stewart et al., 1972; Nier and McElroy, 1977), and data from the Viking lander atmospheric entry trajectories (Seiff and Kirk, 1977). It includes parameterizations to simulate the effects of solar activity, seasonal variation, diurnal variation magnitude, dust storm effects, and effects due to the orbital position of Mars.

## **MARS-GRAM PROFILES OF MEAN TEMPERATURE, PRESSURE AND DENSITY**

Parameterization for the representation of surface temperature and vertical temperature profiles, based on summaries from observational and model data, are discussed in the previous section. The addition of a parameterization for the variations in surface pressure, also discussed in the previous section, then allows for computation of vertical profiles of pressure and density by use of the hydrostatic and perfect gas law relations.

Temperature profiles are built up from parameterizations of the surface temperature and temperature lapse rates between the significant levels set at 5, 15, 30, 50 and 75 km. Parameterization of the spatial and temporal variations of surface temperature were discussed in the previous section. From the summaries of the observational and model data, the spatial and temporal variations of the lapse rates between the significant levels were developed. Temperature profiles are further constrained to be consistent with seasonal and latitudinal variations near 25 km altitude, as presented in Figure 14 of Leovy (1982).

The finally-adjusted temperature lapse rates, appropriate to the specified time and position, are assumed to be constant between each of the significant height levels. With the specification of surface pressure to serve as a boundary condition, the pressure profile is easily computed by integration of the hydrostatic relationship,  $dp/dz = -\rho g = -p g/RT$ , over each of the vertical sections of the constant lapse rate. After a solution for the pressure is obtained, the density is determined from the temperature and pressure by the perfect gas law,  $\rho = p/RT$ . Here  $R$  is the gas constant for a gas of the composition of the atmosphere of Mars and  $g$  is the altitude-dependent value of the acceleration of gravity on Mars (Seiff, 1982).

The Stewart model thermosphere starts with a specification of the temperature  $T_F$  at the base of the thermosphere (at a height  $Z_F$ ). Both  $T_F$  and  $Z_F$  depend on the orbital position of Mars. Between 75 km altitude and height  $Z_F$ , the temperature profile is constructed from a combination of constant lapse rate and constant temperature segments, as necessary to preserve the hydrostatic relationship for pressure between 75 km and height  $Z_F$  (where the Stewart model specifies the pressure to be  $1.26 \times 10^{-4} \text{ N/m}^2$ ). If  $T_F$  is greater than  $T(75 \text{ km})$ , then the temperature profile between 75 km and  $Z_F$  has a constant temperature [=  $T(75 \text{ km})$ ] in the lower part and a constant lapse rate in the upper part. If  $T_F$  is less than  $T(75 \text{ km})$ , then the temperature profile between 75 km and  $Z_F$  is taken to have a constant lapse rate in the lower part and a constant temperature ( $= T_F$ ) in the upper part.

## TERRAIN EFFECTS ON TEMPERATURE PROFILES

A problem in the Martian atmosphere is how to represent the effects of terrain variations on temperature profiles. This problem, as stated by Seiff (1982) is:

"Near the surface, it is necessary to refer the profile to altitude above terrain, as the terrain controls the near-surface temperatures. At higher altitudes also, it is indicated that radiative equilibrium is the first order control over temperature (Seiff and Kirk, 1977) with the input at the lower boundary being radiation from the surface. The surface temperature, in turn, is controlled by solar flux and not the surface elevation. Hence, we have assumed in the model that over extensive regions of depressed or elevated terrain ... the profile [of temperature versus height up to 100 km] ... should be applied at altitudes measured above the terrain. For more local depressions or elevations, the model should be entered at an altitude measured relative to the mean surrounding surface."

Simply put, the Martian air on the mountain tops will not be nearly as cold compared to the air in the valleys as is the case on Earth. Not only is this due to the increased importance of surface radiation, but also due to the fact that the air density is low and airflow over the mountains will not be as effective in moderating the effect of surface radiation on the mountaintop surface to a temperature near that of the approaching, high altitude, cool air flow.

Mars-GRAM treats this problem, as does Seiff, by assuming that the surface temperature is unaffected by terrain variations, and that the vertical temperature profile, relative to the surface temperature, must be specified as a function of height above the local terrain surface.

An example of the interrelationship between surface temperature and temperature profile is seen in the present Mars-GRAM results near the south pole in Figure 11. The strong latitudinal gradient in surface temperature near the polar cap edge is consistent with observations and other models. The corresponding latitudinal gradient in upper level temperatures (e.g. the 25 km temperature of Figure 14 of Leovy, on which Mars-GRAM is based) is not observed to be so large. Therefore there must be a strong latitudinal gradient in near-surface temperature lapse rates in this region near the edge of the polar cap. Details of the effects of surface radiation and terrain elevation on the near-surface temperature profile is an atmospheric boundary layer problem. The boundary layer of the Martian atmosphere has been studied only relatively little (see Sutton et al., 1978, and Kieffer et al., 1976). This problem of temperature effects on near surface temperatures and lapse rates is one which requires further examination in the future.

## WIND PROFILES IN MARS-GRAM

Wind components are evaluated in Mars-GRAM by the geostrophic (or, on Mars, areostrophic) approximation, obtained by a steady balance between pressure gradient and Coriolis forces, namely:

$$u_a = -(1/\rho f) \partial p / \partial y \quad \text{and} \quad v_a = (1/\rho f) \partial p / \partial x, \quad (1)$$

where  $f$  is the Coriolis parameter [ $2\Omega \sin(\theta)$ , where  $\Omega$  is the planetary rotation rate and  $\theta$  is the latitude],  $\rho$  is density, and the pressure gradient components are evaluated by finite differences from pressures evaluated at  $\pm 2.5$  degrees of latitude and longitude from the position at which the wind components are evaluated. Since the areostrophic wind relations (1) follow the thermal wind balance, wind evaluated by these equations, from local horizontal pressure gradients, are consistent with winds evaluated by vertical integration of the thermal wind equations (e.g. compare Figures 13b and 14).

Following Fleming et al. (1988), we take the winds near the equator to be given by

$$u_a = -\{a/[2\rho\Omega\cos(\theta)]\} \partial^2 p / \partial y^2, \quad (2)$$

$$\text{and} \quad v_a = \{a/[2\rho\Omega\cos(\theta)]\} \partial^2 p / \partial x \partial y, \quad (3)$$

where  $a$  is the radial distance from the planetary center, and the winds near the poles ( $|\theta| > 75^\circ$ ) are computed from

$$u_a \cos(\theta)/\cos(75^\circ) \quad \text{and} \quad v_a \cos(\theta)/\cos(75^\circ). \quad (4)$$

Smooth transition between (1), (2) and (3) is accomplished by interpolation between  $\theta = 7.5^\circ$  [at which (2) and (3) apply] and  $\theta = 15^\circ$  [at which (1) applies].

At high altitudes, where the density  $\rho$  becomes low, the areostrophic winds become large because  $\rho$  is in the denominator of equations (1)-(4). To overcome this problem molecular viscosity terms are added to the momentum balance equations, of the form

$$-\nu \partial^2 u / \partial z^2 \equiv -\nu u / L^2 \quad \text{and} \quad -\nu \partial^2 v / \partial z^2 \equiv -\nu v / L^2, \quad (5)$$

where  $\nu = \mu/\rho$ ,  $\mu$  is the molecular viscosity, and  $L$  is a viscous gradient scale (parameterized currently as being equal to the pressure scale height  $H$ ). With the addition of the viscous terms in (5) to the balance between pressure gradient and Coriolis force terms, the viscous-modified areostrophic wind components become

$$u_v = [f^2 u_a - (\nu/L^2) f v_a] / [f^2 + (\nu/L^2)^2], \quad (6a)$$

$$v_v = [f^2 v_a + (\nu/L^2) f u_a] / [f^2 + (\nu/L^2)^2]. \quad (6b)$$

At sufficiently high altitudes that  $(\nu/L^2) \gg f$ , the viscous-modified winds become

$$u_v = -(L^2/\mu)\partial p/\partial x \quad \text{and} \quad v_v = -(L^2/\mu)\partial p/\partial y. \quad (7)$$

The winds evaluated by (7) do not suffer the problem of having density in the denominator, and so do not become too large. The winds evaluated by (7) are orthogonal to the ordinary areostrophic wind components, that is they are parallel to the pressure gradients instead of parallel to the isobars. This approximation is borne out qualitatively by Figure 2 of Bougher et al. (1988), which shows that, on a constant pressure surface, the winds are approximately perpendicular to the isotherms, and hence would be approximately parallel to the pressure gradients on a constant height surface.

Unfortunately the parameterization of equation (6) cannot be tested thoroughly at the present, due to the limitations of the Stewart thermosphere model. Since Stewart's model is intended to be primarily a global mean thermosphere, the horizontal gradients of pressure (as well as those of density and temperature) are too small to be realistic. Thus winds evaluated in the present Mars-GRAM are significantly smaller in magnitude than those produced by the realistic Martian thermospheric model of Bougher et al. (1988).

Near the terrain surface, a simplified boundary layer model for winds is included in Mars-GRAM. In this model the boundary layer winds are estimated by

$$u(z) = [(C_D)^{1/2} / k] \log(z/z_0) u_a, \quad \text{and} \quad (8)$$

$$v(z) = [(C_D)^{1/2} / k] \log(z/z_0) v_a, \quad (9)$$

where the drag coefficient is estimated to be 0.0015, the von Karman constant = 0.4, and the surface roughness is estimated to be 0.03m. If  $z < 1.6$  m (the height of the Viking Lander "surface" wind measurements), then  $z$  is taken to be 1.6 m in equations (8) and (9). The height at which equations (8) and (9) produce winds equal to  $u_a$  and  $v_a$  is taken to be the top of the boundary layer.

## WAVE PERTURBATION MAGNITUDES IN MARS-GRAM

Wave-like perturbations have been observed in the Viking 1 and Viking 2 surface pressure data (Leovy, 1981), in the Mariner 9 IR spectroscopy data (Pirraglia and Conrath, 1974; Conrath, 1976, 1981), and the Viking 1 and Viking 2 lander entry profiles (Seiff and Kirk, 1976, 1977). Most of the wave-like perturbations have been interpreted as atmospheric tides (Pirraglia and Conrath, 1974; Conrath, 1976; Seiff, 1982), or as planetary waves (Conrath, 1981; Barnes and Hollingsworth, 1988). The theory of thermal tides in the Martian atmosphere has been well explored (Zurek, 1976, 1986; Zurek and Haberle, 1988). Compared to the detailed tidal analyses, relatively little attention has been paid to other forms of wave perturbations such as gravity waves (Gadian and Green, 1983), Kelvin waves and normal modes (Zurek, 1988; 1979). The very strong influence of topography on the wave structure in the Martian atmosphere has been documented both by observational data (Conrath, 1976) and by theoretical analysis (Zurek, 1976).

One of the best-known properties of gravity waves is that their amplitudes increase with height as the inverse square root of the mean atmospheric density. In this way, the kinetic energy of the wave is maintained even as the packet propagates upward into the rarer regions. The effect has been likened to the wave-kink that grows as it travels along a whip from the thick end near the handle to the thin region near the tip. The comparison is even more apt than first appears, for just as the

reach heights at which it becomes too large for smooth fluid behavior and it turns over into shocks and/or turbulence.

One of the common sources of gravity waves is wind flow over mountains. As the atmospheric flow reaches the mountain, surface pressures deflect it up and over the mountain rise, and then restore it to level on the other side. However, the disturbance transmitted to the air flow is not confined to some surface region, as the pressure fields associated with the deflection have space and time scales that match the characteristics of gravity waves in the free atmosphere. Distorting any elastic medium in a way that matches its natural modes causes the excitation of waves that broadcast energy from the disturbance to the far reaches of the medium. So, around mountainous regions the atmosphere normally contains a wealth of wave activity. Mountain waves, especially the resonant forms known as lee waves are a familiar phenomenon of the Earth's atmosphere, and are expected to be of even more importance in the Martian atmosphere.

Because erosion is much weaker in the rainless Martian environment, and because surface gravity is lower, surface features on Mars tend to be more severe than on Earth. Ridges and mountains are higher, while surface winds are comparable (and, at times, higher), so the Martian mountain waves provide stronger aerodynamic disturbances than are encountered on Earth.

The waves of most interest for aerobraking or lander vehicle entry are readily modeled by the long-wave approximation. This component of the disturbance maps up through the atmosphere as a replica of the underlying terrain, and, in common with all gravity waves, the associated fractional density disturbances grow ever greater with altitude. Effectively the probing spacecraft will be "flying into the mountains", even when it is several tens of kilometers above the peaks. Limits may be imposed by wave saturation (Smith et al., 1987), absorption by critical layers (Hines, 1960), or by dissipation of the waves by molecular viscosity (Pitteway and Hines, 1963), but over the larger terrain features the tops of these ghost mountains may occur as shocks or wedges of turbulence.

In the long-wave approximation, we assume that the wave number  $k$  satisfies the inequality

$$k^2 \ll N^2/U^2 \quad , \quad (10)$$

where  $N$  is the Brunt-Vaisala frequency, and  $U$  is the mean wind speed. Under this assumption the governing differential equation for wave perturbations is

$$d^2y/dz^2 + [N^2/U^2 - (d^2U/dz^2)/U - 1/4H^2]y(z) = 0 \quad , \quad (11)$$

where  $H$  is the atmospheric scale height. The Fourier transform,  $w(z)$ , for the vertical velocity perturbations is, for example, given by

$$w(z) = \rho_0(z)^{-1/2} A(k) y(z) \quad , \quad (12)$$

where  $\rho_0$  is the mean density,  $A(k)$  is presently an unknown Fourier amplitude, and  $y(z)$  is the solution obtained from equation (11).

The assumption of purely tangential flow for the surface boundary condition determines the wave amplitude in terms of the slope  $dh/dx$  of the surface terrain and the mean wind speed  $U(0)$  that must be deflected over the terrain undulation. The Fourier transform of this surface condition defines

the component amplitudes  $A(k)$  of equation (12) through the Fourier components of the surface terrain shape,  $h(x)$ .

From this approach, the Fourier transform of the density variations can be obtained. Since there is no  $k$  dependence for the coefficients relating the Fourier transform of the density to the Fourier transform of the terrain surface, the Fourier inversion to obtain the vertical profile of density perturbations is straightforward, and yields

$$\rho_w(x, z) / \rho_o = \left[ \frac{y(z)U(0)N^2 \left( \frac{\rho_o(0)}{\rho_o(z)} \right)^{1/2}}{y(0)U(z)g} \right] h(x) \quad , \quad (13)$$

The implications of equation (13) are clear:

- (a) The horizontal structure of the density disturbance  $\rho_w$  is an image of the terrain shape  $h(x)$ .
- (b) There is the standard vertical growth factor associated with gravity waves, proportional to the inverse square root of the mean density.
- (c) There is a vertical wave structure  $y(z)/y(0)$ , which will usually be closely sinusoidal.
- (d) There is an excitation factor  $[U(0)N^2/U(z)g]$  relating surface conditions to the generated wave density field.

These results apply equally to an isolated surface feature, such as a mountain sitting alone in the plains region, or an extended complex area of severe terrain. If the surface shape is known, and one differential equation involving the meteorological functions  $U(z)$  and  $N(z)$  is solved, the density perturbation,  $\rho_w(x, z)$ , at any location above the surface is obtained. Although derived here for the two-dimensional case, the results of equation (13) can easily be generalized to a fully three-dimensional terrain description.

If non-linear processes do not limit the growth of the wave, the high kinematic molecular viscosity of the upper atmosphere will. Because of lower density, the molecular viscosity effect will be felt at lower altitudes on Mars than on Earth. The treatment of Pitteway and Hines (1963), can be used to model this effect.

If a WKB approximation solution is applied for (11) and (13), the amplitude of the density perturbations due to the mountain waves can be approximated as

$$|\rho_w(x, z)| / \rho_o = \left[ \frac{N(0)N(z)}{g} \left( \frac{\rho_o(0)}{\rho_o(z)} \right)^{1/2} \right] h(x) \quad . \quad (14)$$

This form of the solution eliminates the explicit dependence on  $U(z)$  and  $U(0)$ , so that all of the terms in (14) are readily evaluated by Mars-GRAM from the terrain height data and the thermodynamic parameterization models. This relation [with the terrain relief  $h(x)$  somewhat exaggerated because of the present coarse resolution used] is employed in Mars-GRAM to estimate the magnitude of the random density perturbation component below 75 km altitude.

In order to insure that the magnitudes estimated by (14) do not become too large [because of the  $\rho_o(z)$  term in the denominator], a viscous damping model must also be applied here, as well as to the areostrophic wind components. Following the approach of Pitteway and Hines (1963), an approximate solution for the damping factor (appropriate in the long-wave limit), to be applied as a factor to equation (14), is obtained as

$$\exp\{-[L_h \nu N^3 H/(4\pi U^4)] [1 - \rho_o(z) / \rho_o(0)]\} \quad , \quad (15)$$

where  $L_h$  is the horizontal wavelength of the dominant mode of the mountain waves.  $L_h$  is taken to be the same as the horizontal scale used in the density perturbation model (see next section).

Relations (14) and (15) are used to estimate the density perturbation magnitudes up to a height of 75 km. Above the base of the thermosphere (at height  $Z_F$ ), the short-term density perturbation magnitudes of the Stewart model are employed. Between 75 km and  $Z_F$ , interpolation is used to insure a smooth transition between these two height regions.

### DENSITY PERTURBATION SIMULATION IN MARS-GRAM

The same density perturbation model used in the Earth GRAM program can be utilized in Mars-GRAM, provided that the perturbation magnitudes, horizontal scales, and vertical scales are adapted to values applicable for the Martian atmosphere. The density perturbation model estimates relative density perturbations  $\rho'(x,y,z,t)$  by the relation

$$\rho'(x+\Delta x, y+\Delta y, z+\Delta z, t+\Delta t) = \alpha \rho'(x,y,z,t) + \beta R(x,y,z,t) \quad , \quad (16)$$

where  $\alpha$  is the correlation  $r(\Delta x, \Delta y, \Delta z)$  over the spatial separation involved between steps, given by

$$r(\Delta x, \Delta y, \Delta z) = \exp\{-[(\Delta x/L_h)^2 + (\Delta y/L_h)^2 + (\Delta z/L_z)^2]^{1/2}\} \quad , \quad (17)$$

$\beta$  is given by  $[1 - \alpha^2]^{1/2}$ , and  $R(x,y,z,t)$  is a normally-distributed uncorrelated random sequence, having the same rms magnitude as the relative density perturbations  $\rho'$ .

Evaluation of the magnitudes of the density perturbations used in Mars-GRAM were discussed in the previous section. The vertical scale for the density perturbations,  $L_z$ , was estimated from structure-function analysis of the Viking 1 and Viking 2 density profiles (Seiff and Kirk, 1977) to be 8 km, at least for altitudes up to 100 km. For the horizontal scale of the density perturbations,  $L_h$ , the values used in the Earth GRAM model were scaled by a factor of 1.5, as estimated to be applicable for the Martian atmosphere. Namely, in Mars-GRAM we take

$$L_h = 30 + 0.01875 z^2 \quad , \quad (18)$$



with  $z$  and  $L_h$  in km. An upper limit of 600 km is imposed for  $L_h$  at high altitudes.

## CONCLUSIONS

The Mars-GRAM has numerous applications as a "poor man's global circulation model". For example, the computation of all of the data necessary to describe the complete seasonal variations at the surface (Figures 1-3) and all altitudes (e.g., Figure 9), takes at most a few minutes on an IBM-PC (with 8087 co-processor; even faster on an 80286-based machine, such as an IBM-AT or compatible, or on an 80386-based machine). Comparable data would take many hours of computation on a mainframe using a 3-D global circulation model for Mars. The diurnal (longitudinal) variability incorporated into the Mars-GRAM program is not even available in 2-D version of a Mars global circulation model.

In addition to the engineering applications envisioned for Mars-GRAM (e.g., aerocapture mission profile studies, Mars Rover Sample Return mission planning and design), the Mars-GRAM has a number of potential scientific applications. One of these is its ability to provide a realistic, geographically and seasonally-dependent background of temperatures and winds for studies of tides and the atmospheric propagation of other wave disturbances (e.g., gravity waves, mountain lee waves, etc.). Another application would be in providing realistic "first guess" profiles for the inversion processing for temperature retrievals from temperature sounders on upcoming Mars missions.

Of course, being a parameterization model, rather than a first principles one such as a global circulation model, Mars-GRAM is only as good as the parameterizations built into it. Also it cannot test the sensitivity to variation of parameters beyond those on which the parameterizations are based (e.g., it cannot estimate the effects of a dust storm of twice the optical depth previously observed). With continued analysis of additional observational data from the Viking and Mariner programs, analysis of new results from global circulation models, and with new data expected to be coming in from the Mars Observer program, Mars-GRAM should steadily improve in its realism and reliability in the future.

## PLANS FOR FUTURE IMPROVEMENTS IN MARS-GRAM

Although the goal of producing a fairly realistic model of the Martian atmosphere has been realized in the current version of Mars-GRAM, there is still room for substantial improvement and enhancement of the program. There is a considerable volume of computerized data, from the Mariner and Viking programs, available at government and university planetary studies laboratories around the country. As discussed in the previous section, since the current Mars-GRAM parameterizations were developed only from the limited amount of data and information in the open literature, there is room for considerable improvement in these parameterizations by analysis of these considerable-sized computer data bases.

As discussed in the section of winds in the thermosphere, there is considerable room for improvement in the horizontal gradients of density, temperature and pressure in the thermospheric model. Simple parameterizations of the latitudinal and longitudinal (diurnal) variations of temperature could be developed from the realistic thermospheric simulations of the model of Bougher et al. (1988) (e.g., see their Figures 3 and 4). The current approach of the Stewart thermospheric model should then be adequate for estimating density and pressure from these improved thermospheric temperature estimates.

Since the current Mars-GRAM relies on estimates of the daily total surface solar irradiance for the estimation of daily maximum, average and minimum temperatures, it would be a straightforward addition to Mars-GRAM to add a subroutine which calculates the direct (beam) and diffuse (scattered) components of the time-dependent solar irradiance at the surface. Such a routine for estimation on the surface solar irradiance would be based on the model approach of Justus and Paris (1985), with parameters adapted for conditions of the Mars atmosphere and dust optical properties. The influence on solar irradiance due to dust storm conditions could easily be incorporated, since optical depth has been measured at the Viking Lander sites (Tillman et al., 1979; Zurek, 1982), and other dust optical properties have also been inferred (Toon et al., 1977). Addition of a surface solar irradiance module for Mars-GRAM would be very useful for such applications as: (1) analysis of thermal heating environments and solar power cell performance on surface-based systems, such as Mars Rover, (2) analysis of heating, life and trajectory for balloon systems, such as that proposed for the Soviet Mars 1994 mission, and (3) for general improvements in the capability to parameterize and study the Planetary Boundary Layer of Mars and its energy and momentum flux budgets.

Users or potential users of Mars-GRAM who are interested in the possibility of one or more of these modifications being incorporated into the program are asked to contact either Dr. Justus at Computer Sciences Corporation or Mr. Dale Johnson at NASA Marshall Space Flight Center.

## **ACKNOWLEDGMENTS**

The authors wish to express appreciation to Mr. Joe Gamble and Dr. David Kaplan, of NASA Johnson Space Center for their encouragement (and monetary support) of the Mars-GRAM development program. Thanks are also due to Mr. Omar Torres, of Georgia Tech, who provided valuable assistance in reading data from graphs in the published literature and in the development of the surface pressure parameterizations used in Mars-GRAM.

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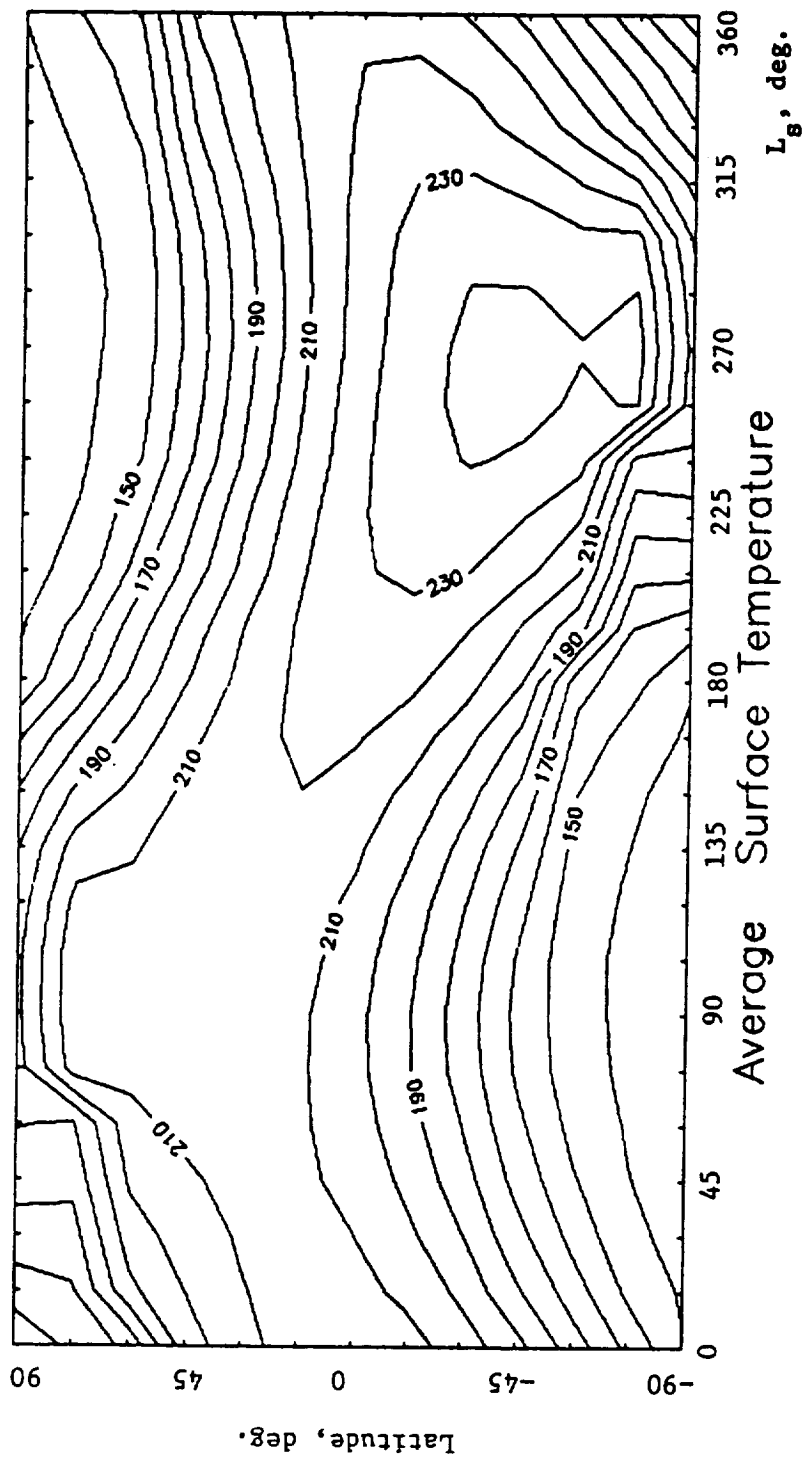


Figure 1 - Seasonal and latitudinal variation of daily average surface temperature, computed by the MARS-GRAM model.  $L_s$  is the areocentric longitude of the sun.

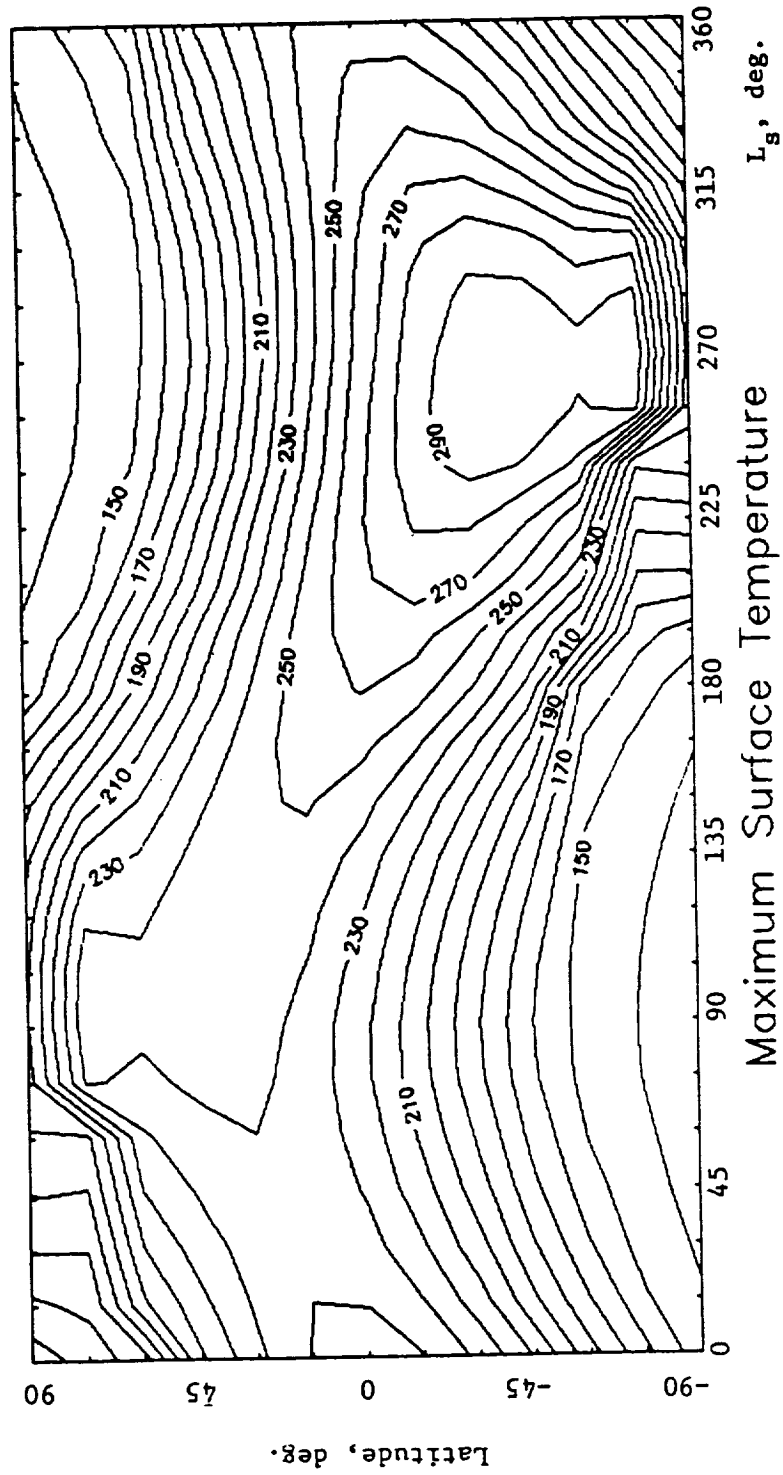


Figure 2 - Seasonal and latitudinal variation of daily maximum surface temperature, computed by the MARS-GRAM model.

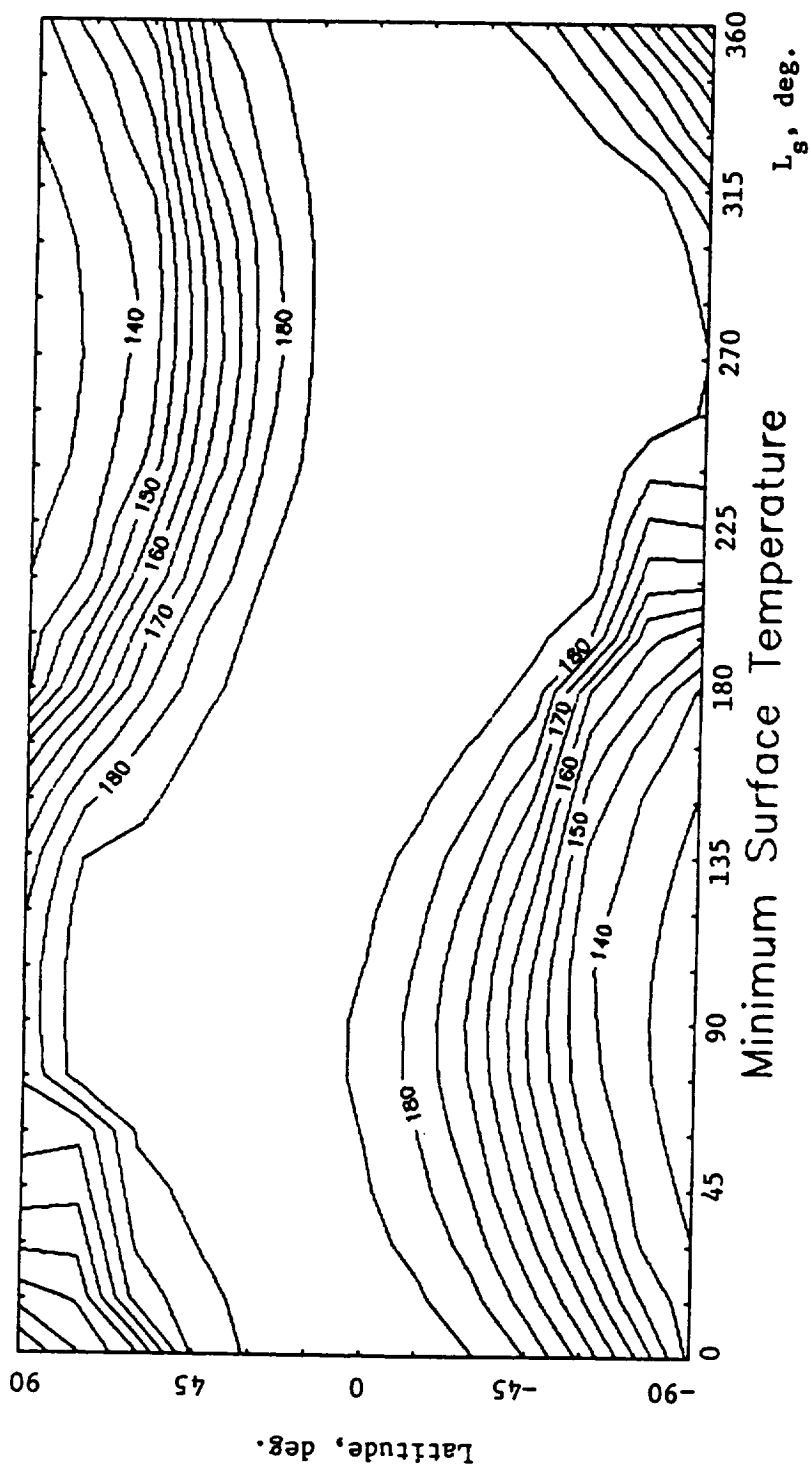
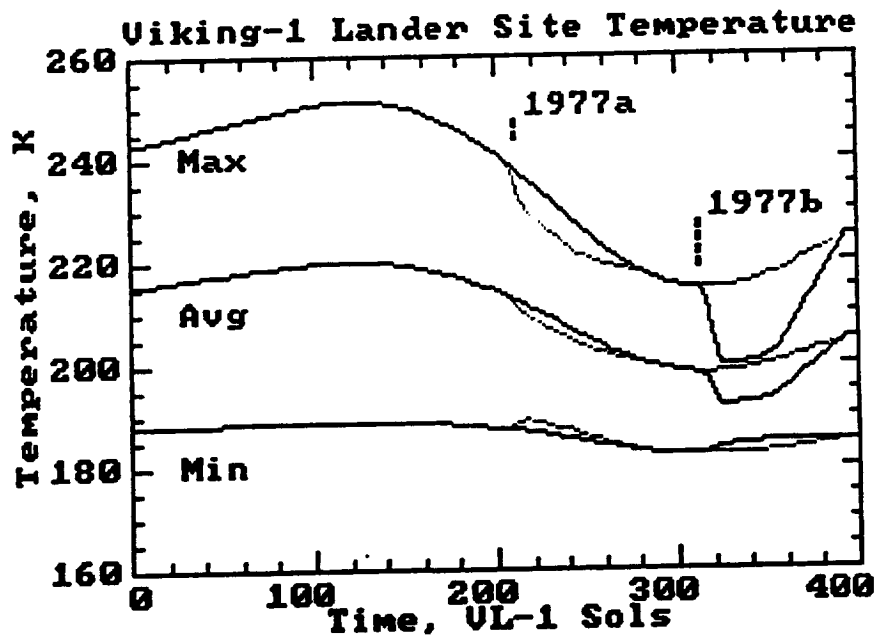
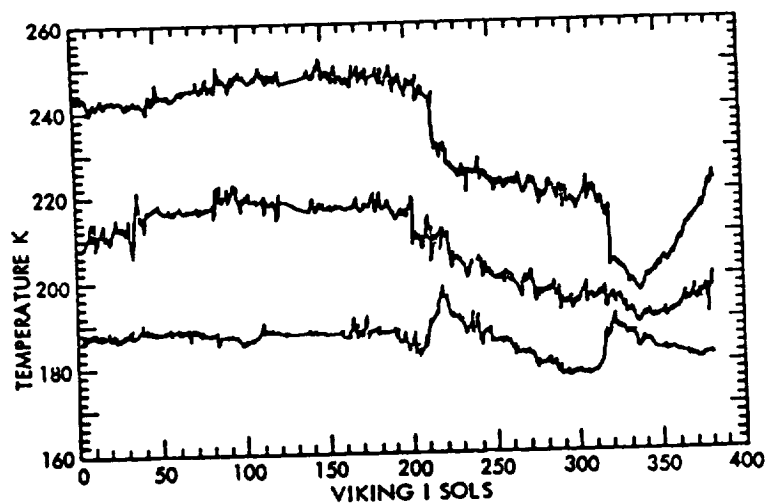


Figure 3 - Seasonal and latitudinal variation of daily minimum surface temperature, computed by the MARS-GRAM model.

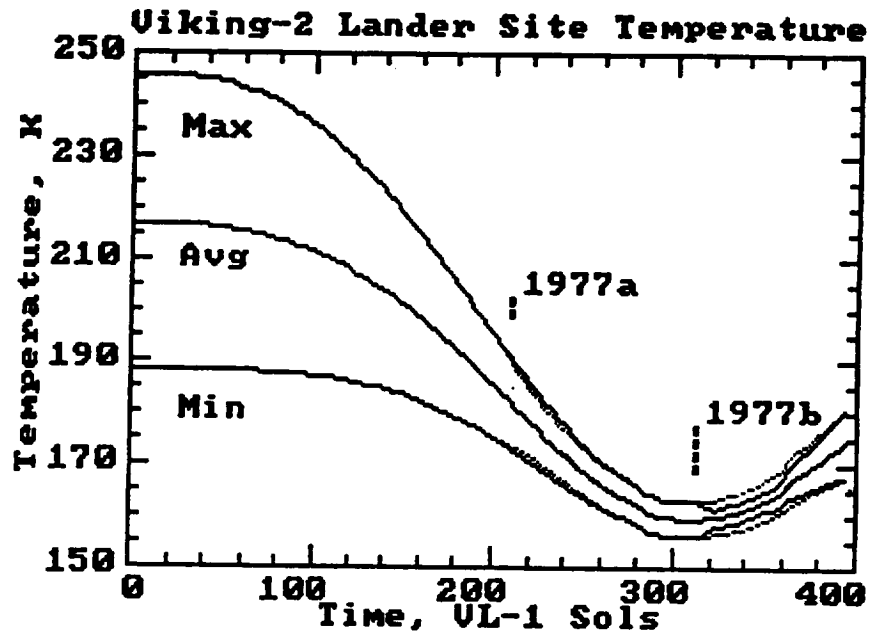


a)

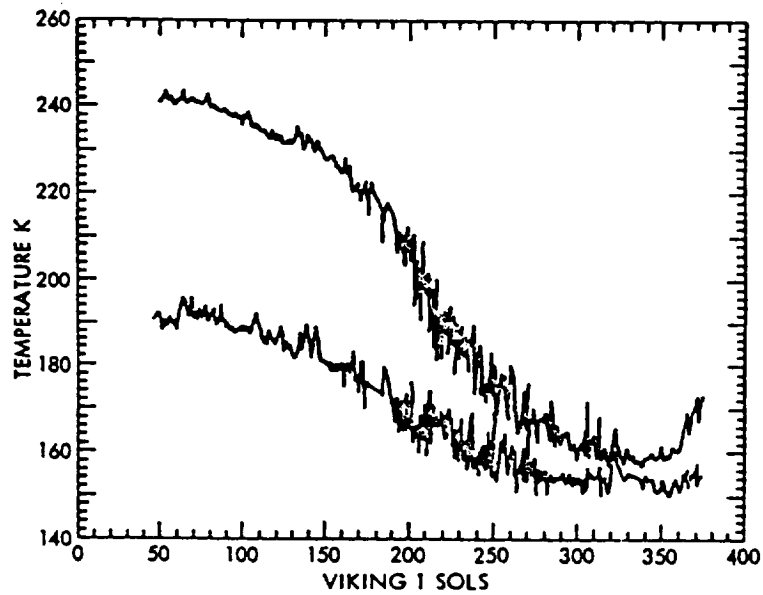


b)

Figure 4 - Seasonal variation of the daily maximum, mean, and minimum temperature at the Viking Lander 1 site (a) computed by MARS-GRAM, and (b) as reported by Ryan and Henry (1979).

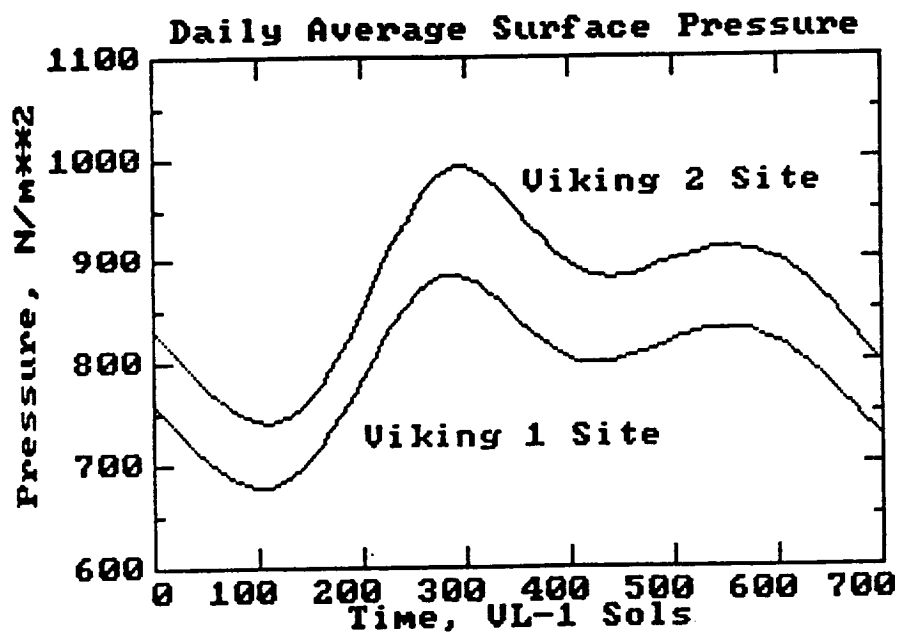


a)

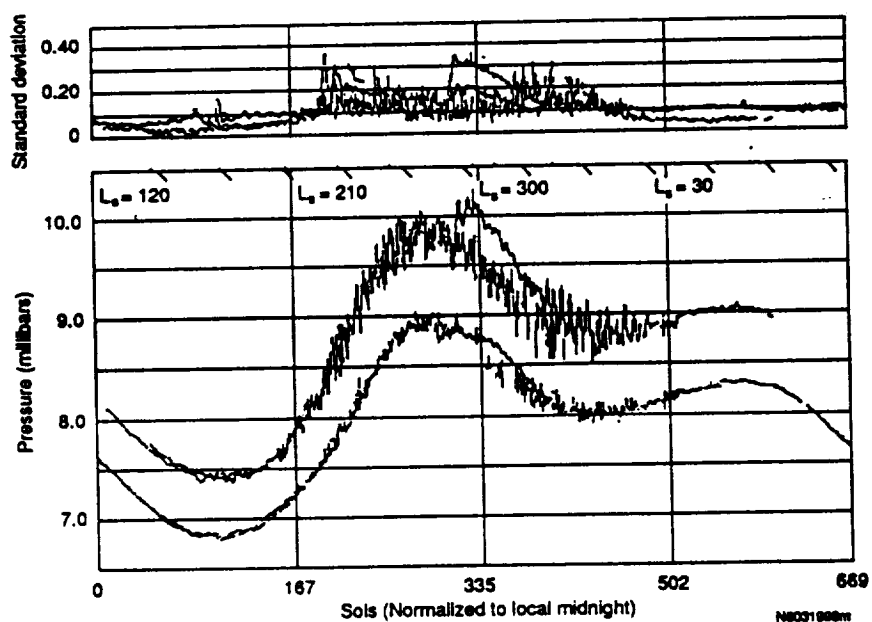


b)

Figure 5 - Seasonal variation of the daily maximum, mean, and minimum temperature at the Viking Lander 2 site (a) computed by MARS-GRAM, and (b) as reported by Ryan and Henry (1979).



a)



b)

Figure 6 - Seasonal variation of the daily average surface pressure at the Viking 1 and 2 Lander sites (a) computed by Mars-GRAM, and (b) as reported by Tillman (1988).

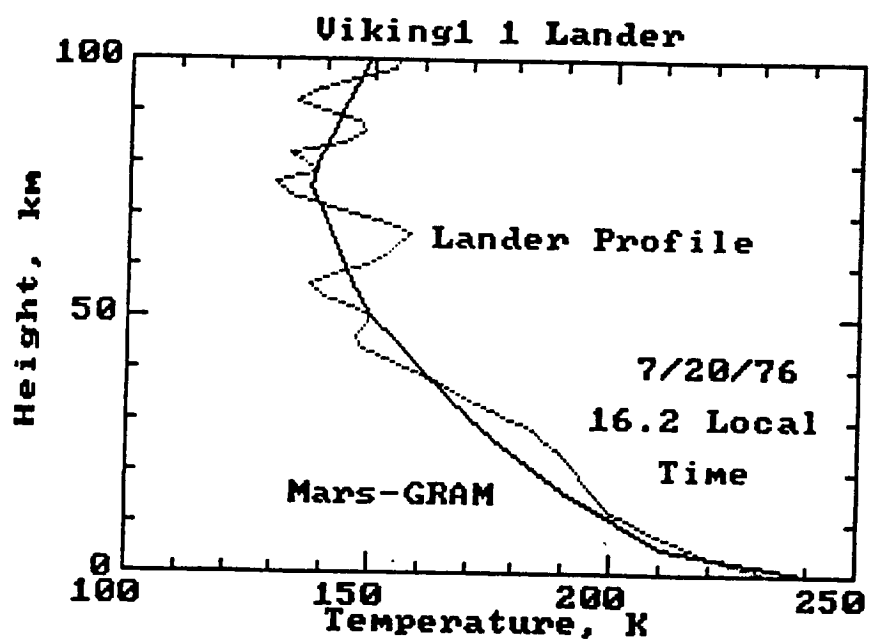


Figure 7 - Vertical temperature profile simulated by Mars-GRAM for date, time and position of Viking 1 Lander site (solid line) and measured Viking 1 Lander profile (dotted line).

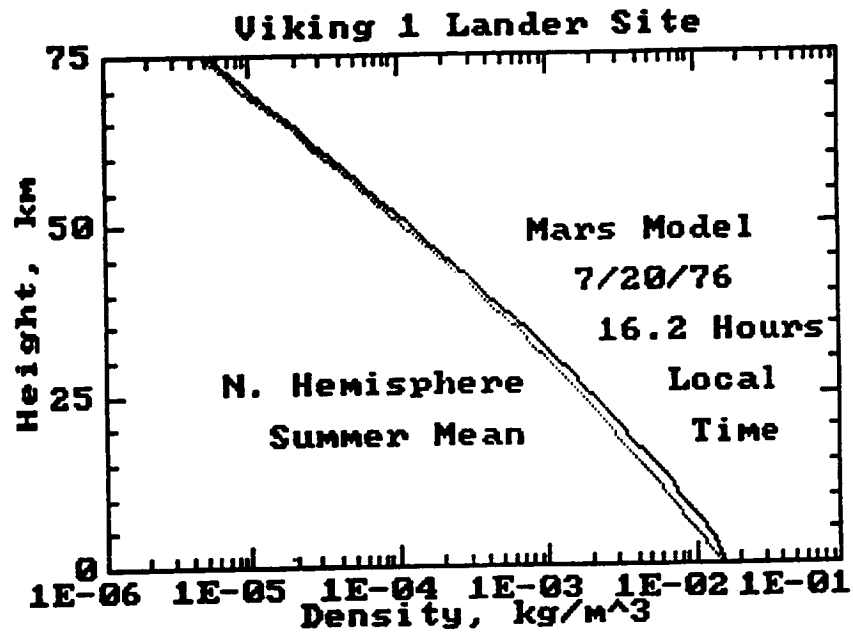


Figure 8 - Vertical profile of density simulated by the Mars-GRAM for date, time and position of the Viking 1 Lander site (solid line) and the COSPAR model for Northern Hemisphere summer mean conditions (dotted line).



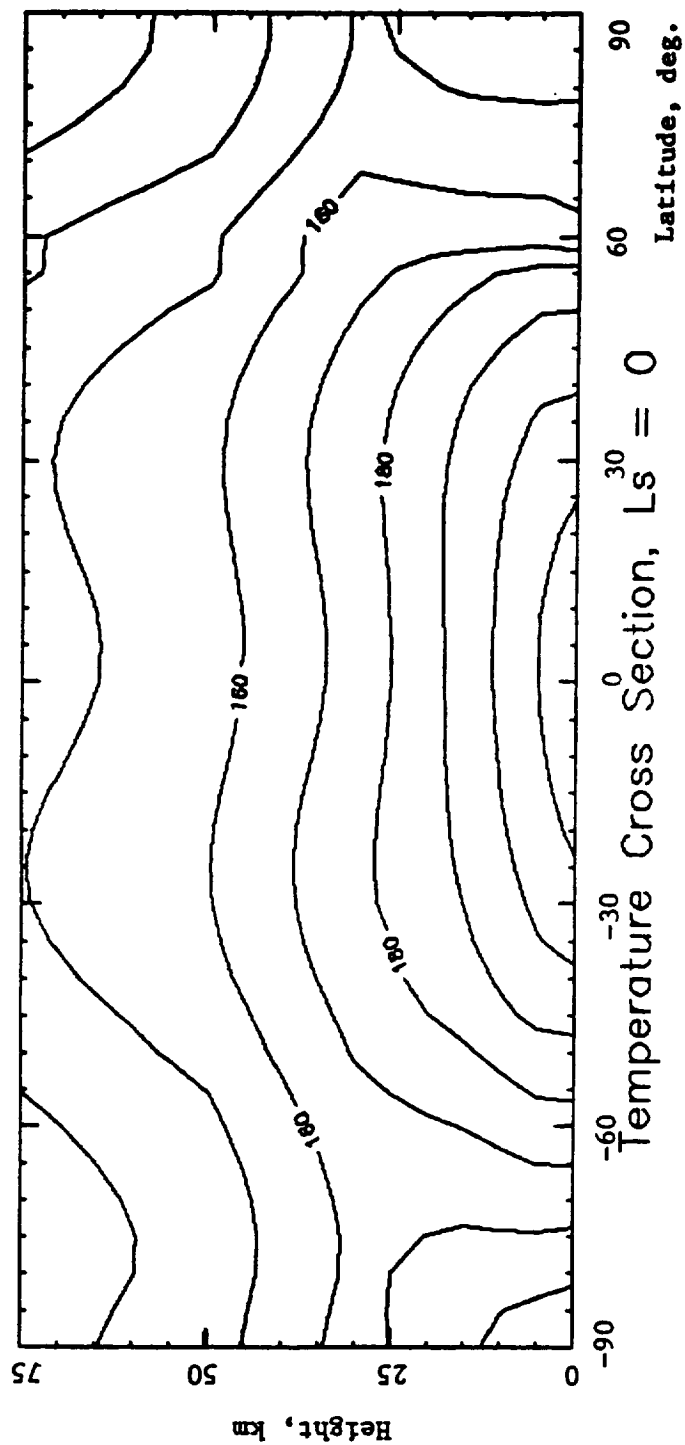


Figure 9 - Height and latitudinal variation of daily mean temperature at Northern Hemisphere spring Equinox (areocentric longitude of sun  $L_s = 0^\circ$ ) for dust-free conditions, as computed by Mars-GRAM,

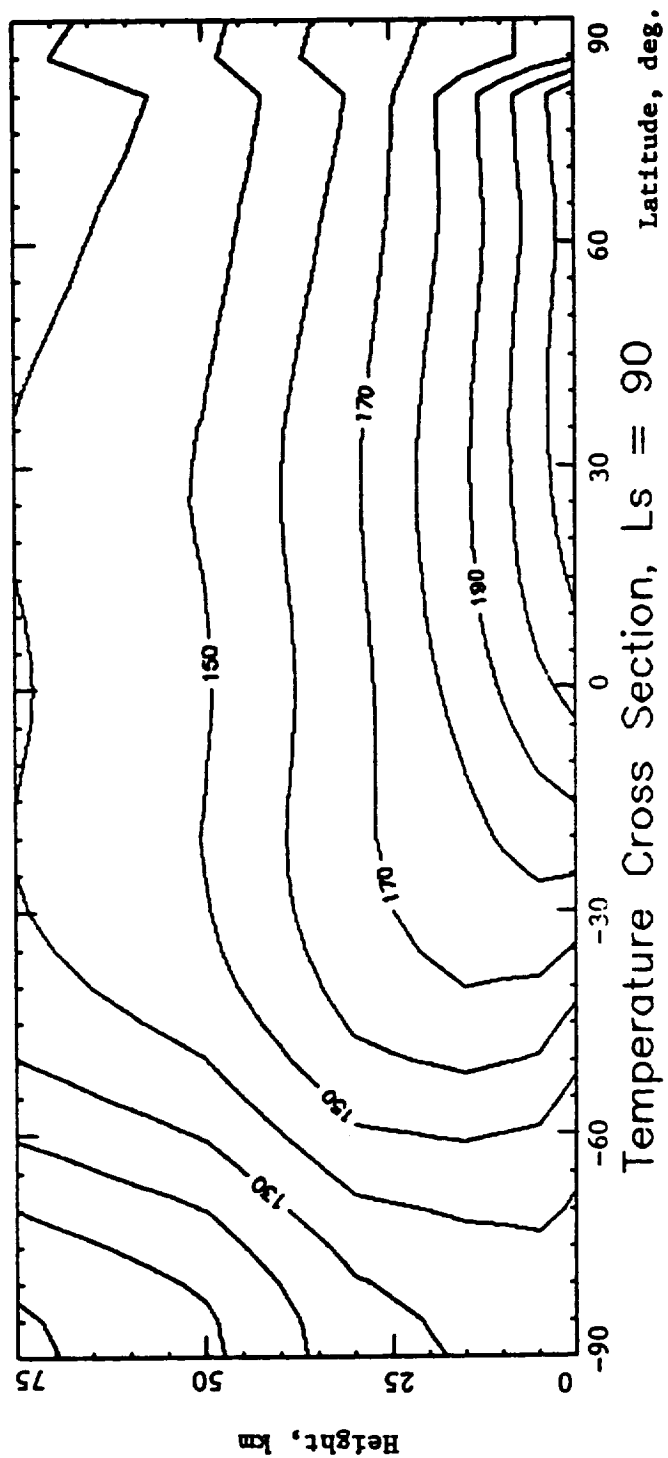


Figure 10 - Height and latitudinal variation of daily mean temperature at Northern Hemisphere summer solstice ( $L_s = 90^\circ$ ) for dust-free conditions, as computed by Mars-GRAM.

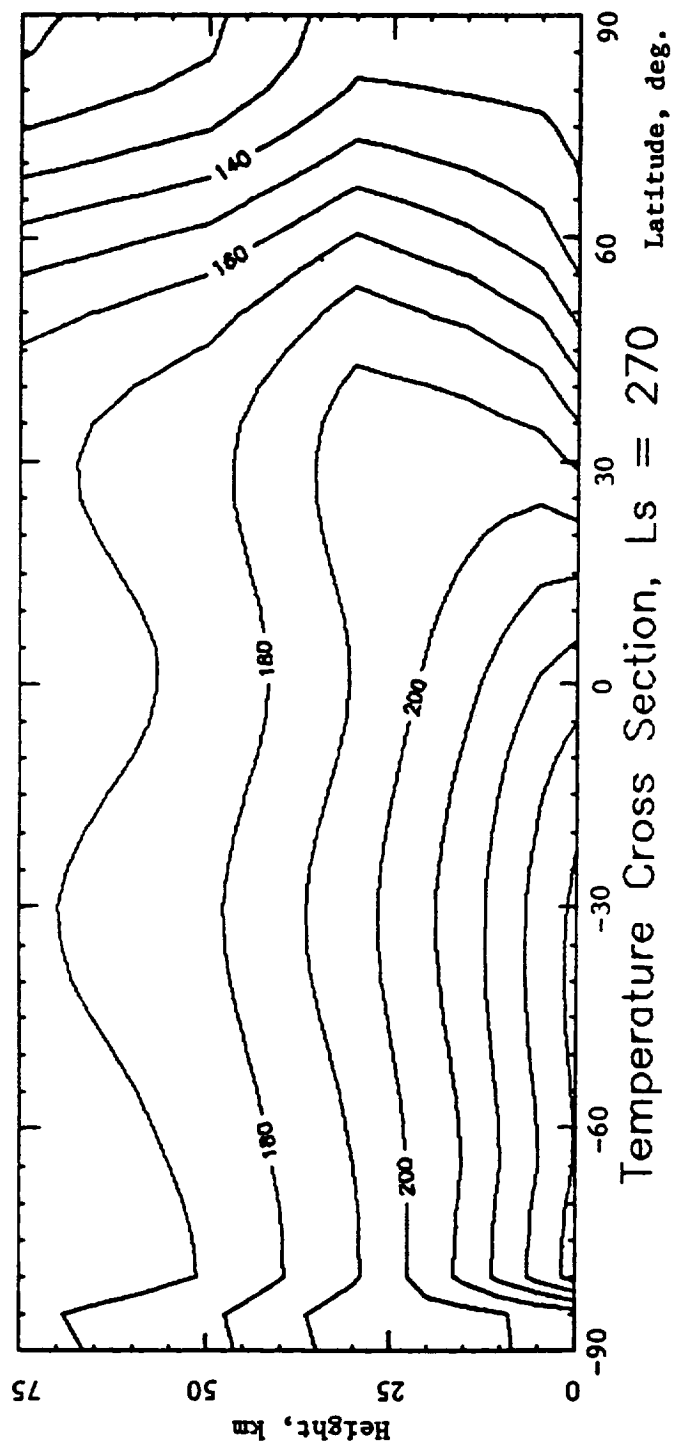


Figure 11 - Height and latitudinal variation of daily mean temperature at Northern Hemisphere winter solstice ( $L_s = 270^\circ$ ) for dust-free conditions, computed by Mars-GRAM.

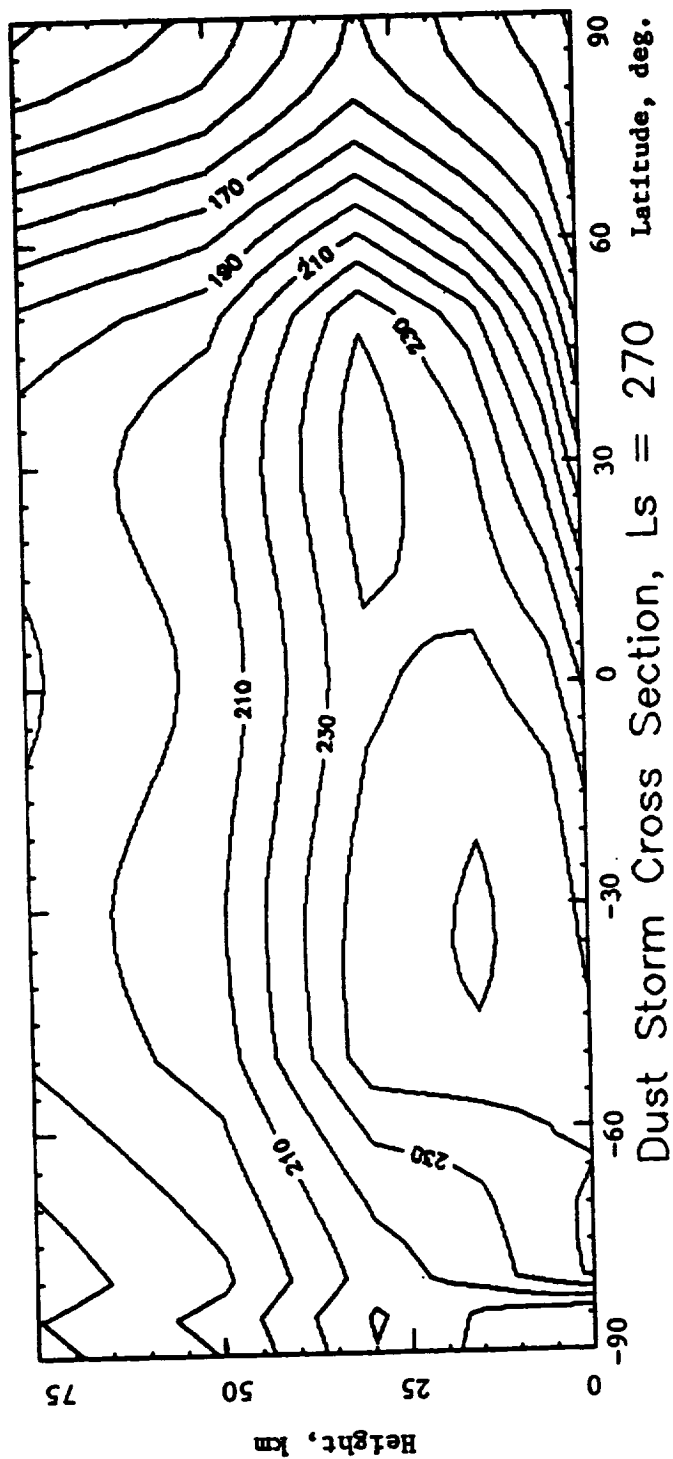
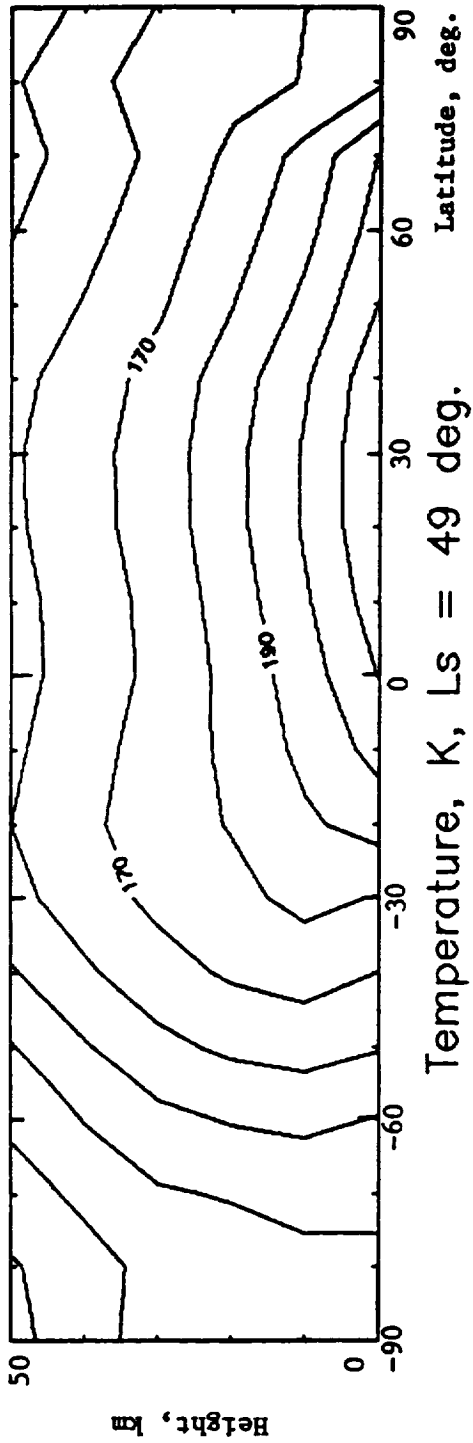
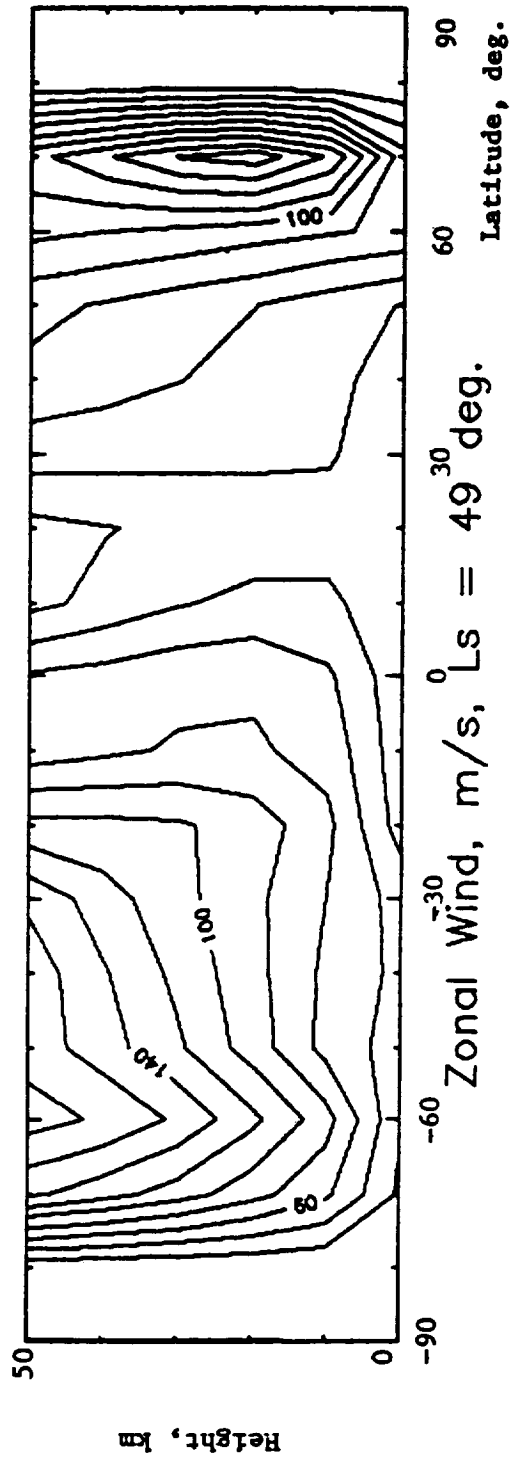


Figure 12 - Height and latitudinal variation of daily mean temperature at Northern Hemisphere winter solstice for a fully-developed global dust storm (intensity 3.0), computed by Mars-GRAM.



a)



b)

Figure 13 - Cross section of (a) temperature (K) and (b) zonal wind (m/s) at 9 am local time for  $L_s = 49^\circ$ .

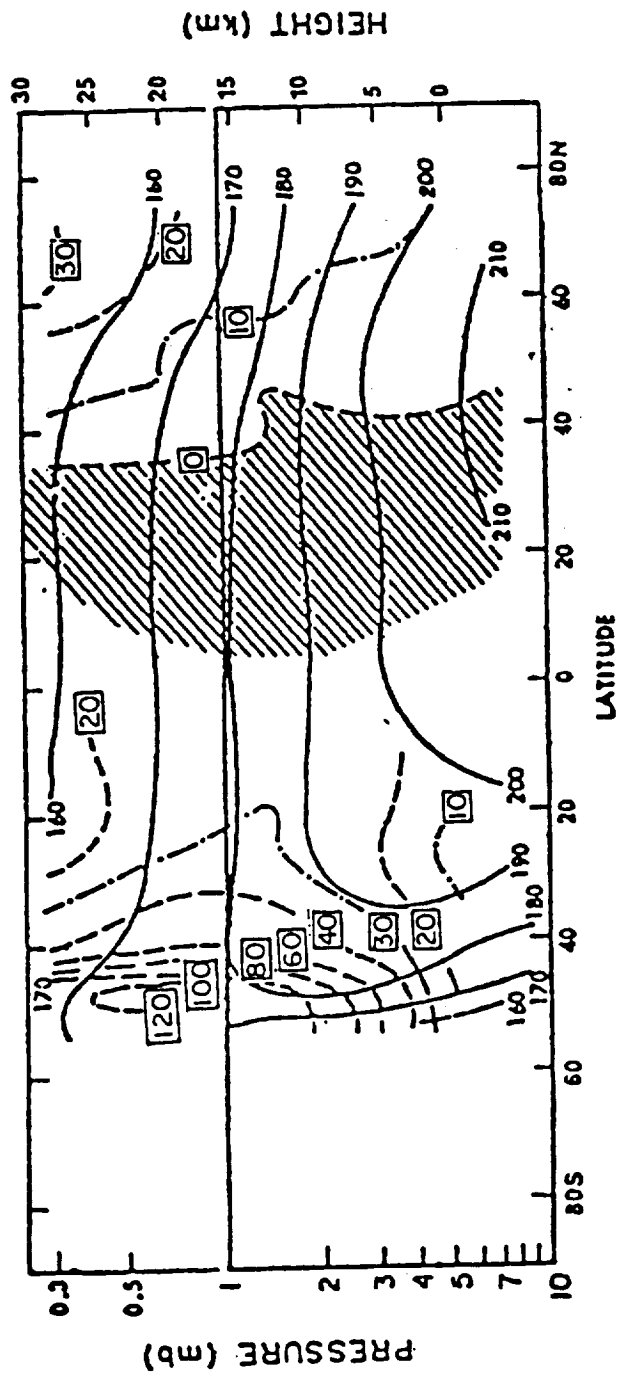


Figure 14 - Cross section of zonally-averaged temperature (K) and geostrophic zonal wind ( $\text{m s}^{-1}$ ) based on Mariner 9 IRIS data between  $L_s = 43$  and  $L_s = 54$  (approximately early May in analogous terrestrial season), Leovy (1982), from data provided by B. Conrath.

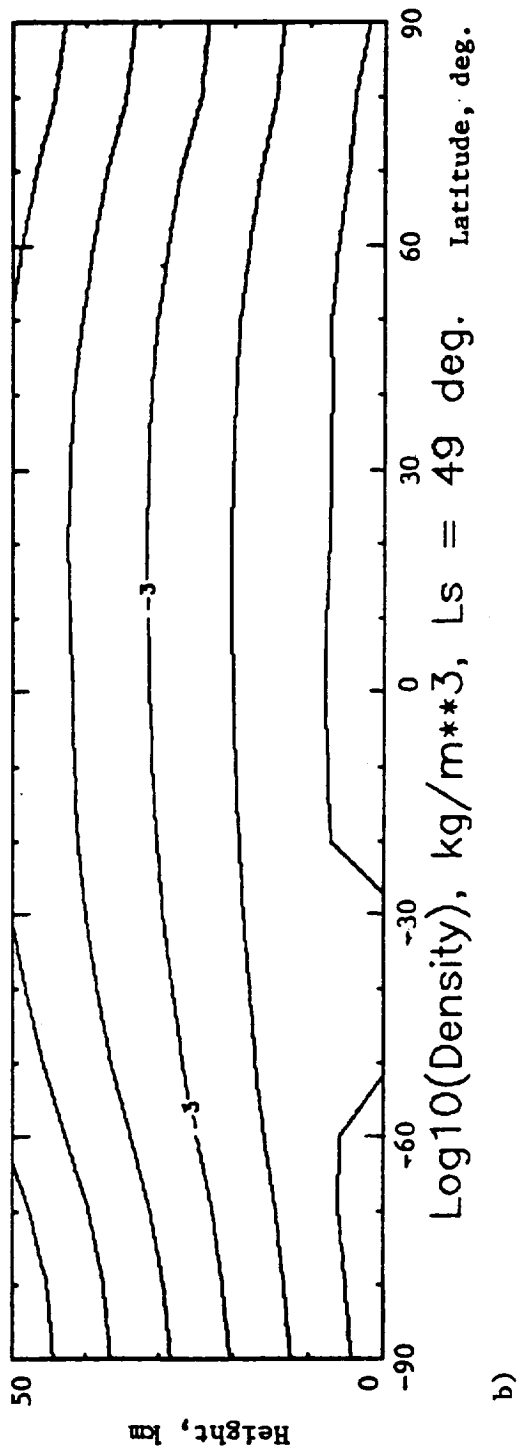
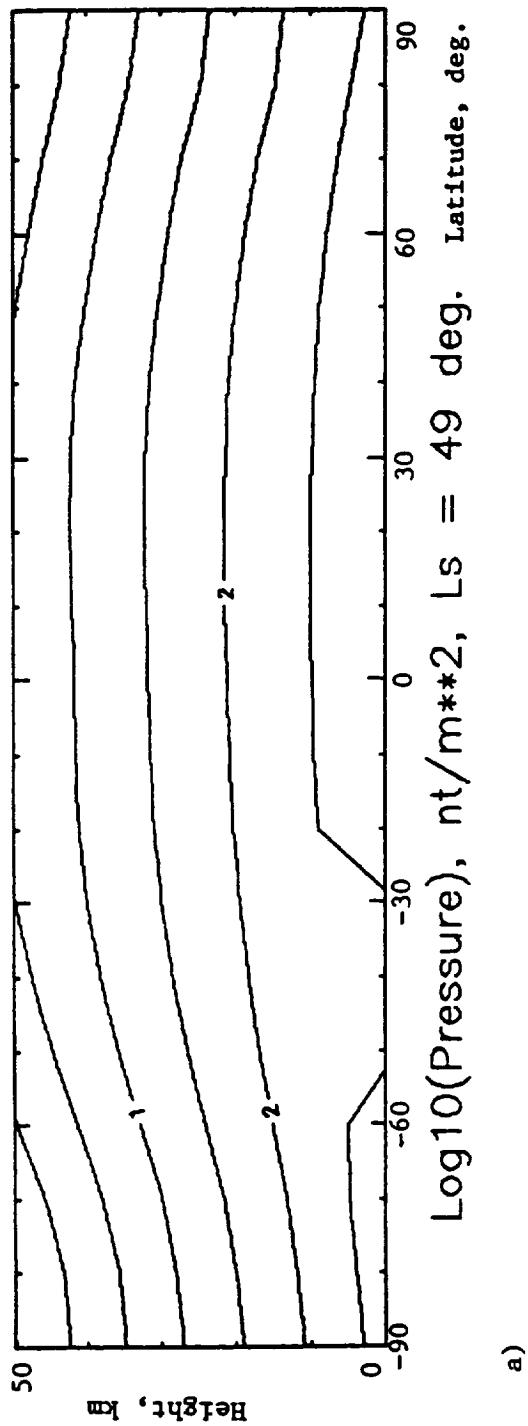


Figure 15 - Cross sections of (a) log-base-10 pressure ( $\text{N/m}^2$ ) and (b) log-base-10 density ( $\text{kg/m}^3$ ) at 9 am local time for  $L_s = 49^\circ$ .

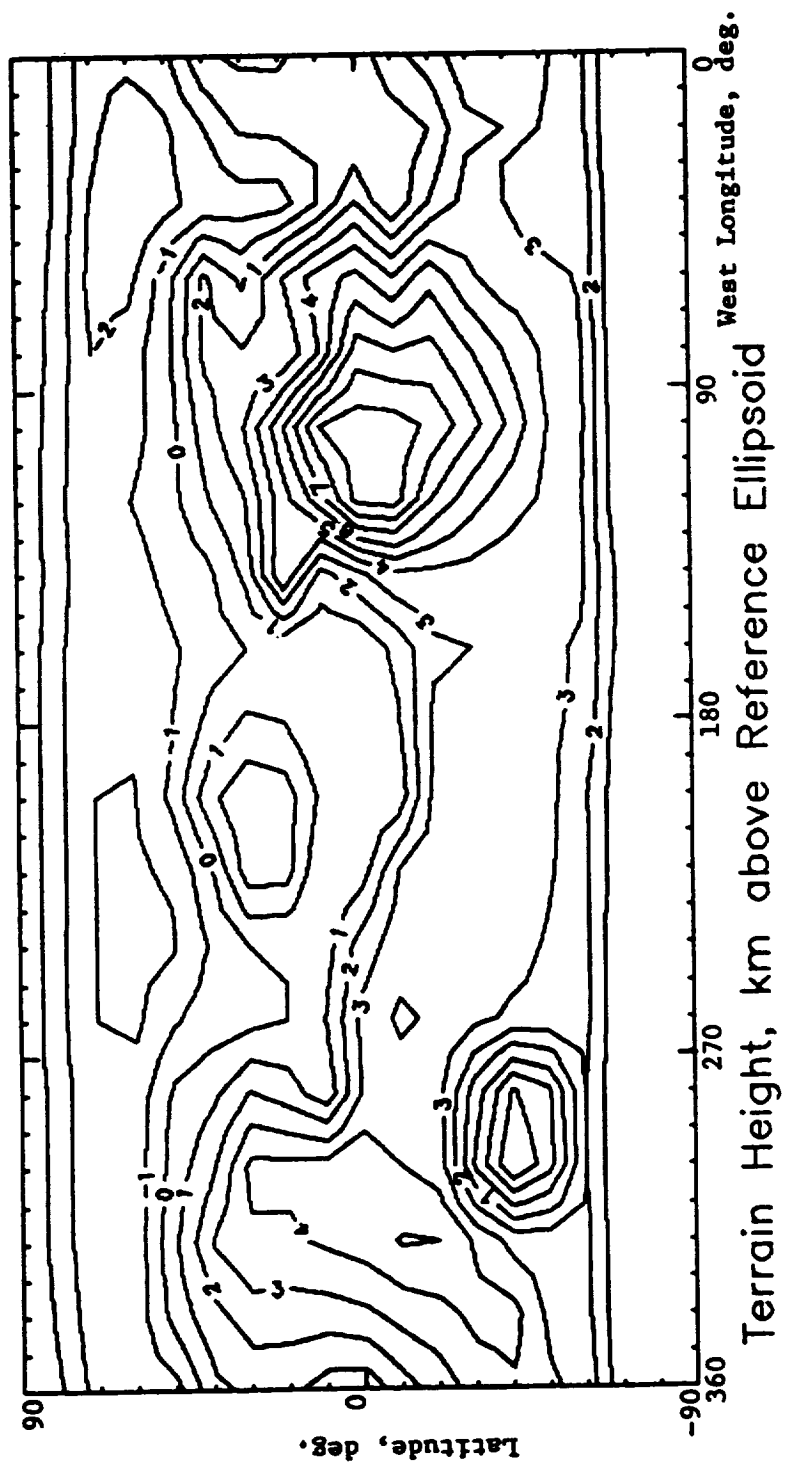


Figure 16 - Contours of local surface terrain height, relative to reference ellipsoid (km) at 10° latitude by 20° longitude resolution.



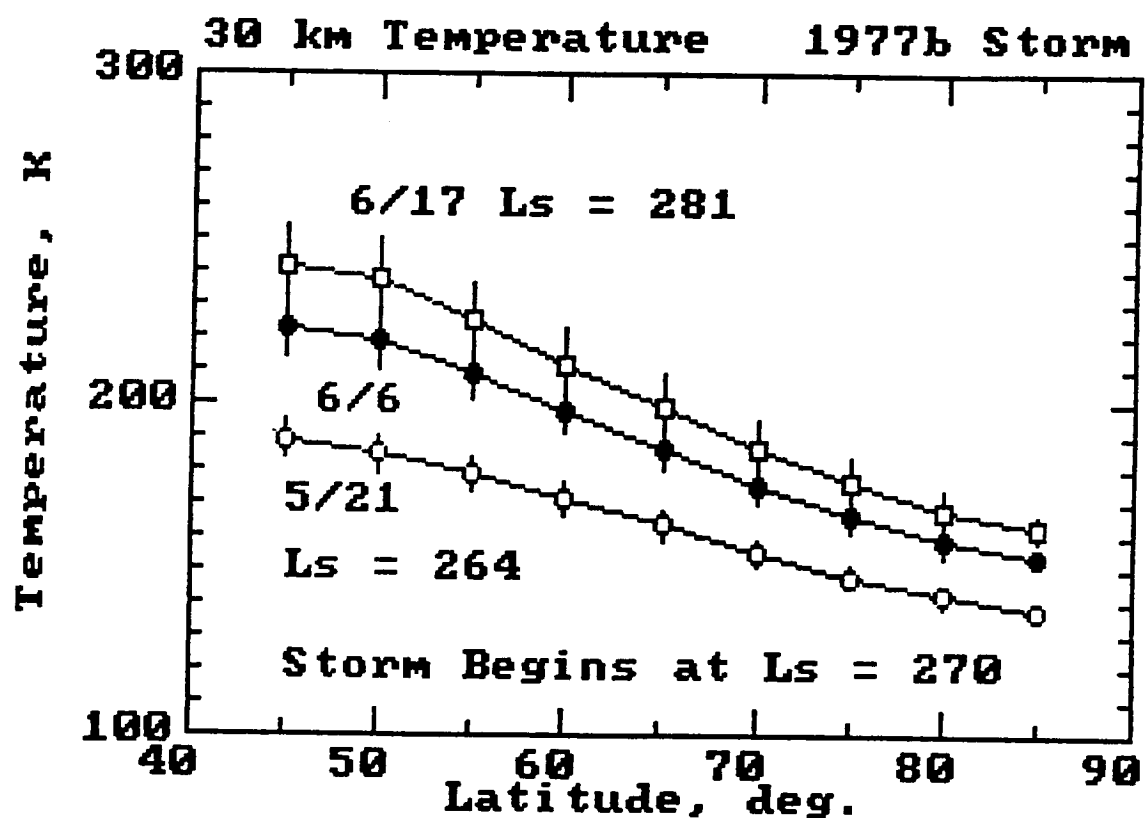


Figure 17 - Progression of simulated dust-storm effect on daily average, maximum and minimum temperature versus latitude and  $L_s$  value (degrees) for the 1977b storm.

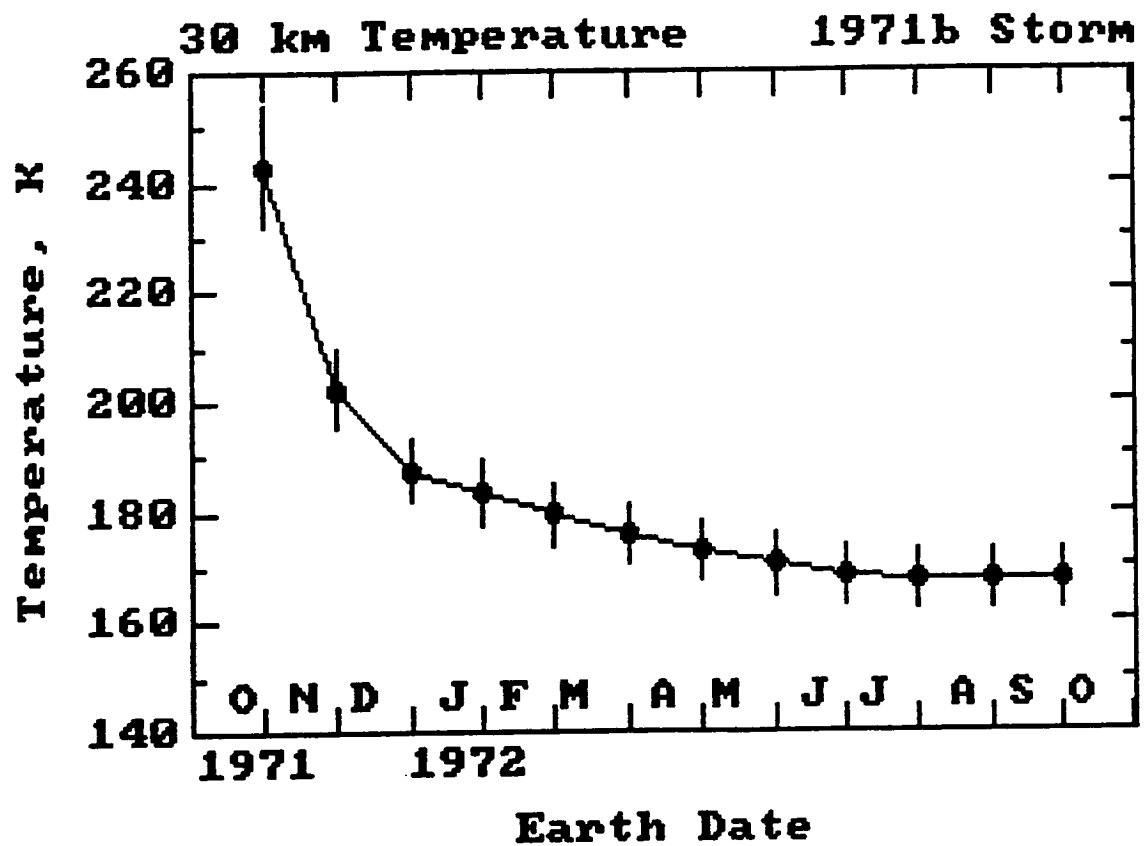


Figure 18 - Progression of simulated dust-storm effect on daily average, maximum and minimum temperature versus time at latitude 25°S for the 1971b storm.

## **ABSTRACT**

Three major additions or modifications have been made to the Mars Global Reference Atmospheric Model (Mars-GRAM). (1) In addition to the interactive version, a new batch version is available, which uses NAMELIST input, and is completely modular, so that the main driver program can easily be replaced by any calling program, such as a trajectory simulation program. (2) Both the interactive and batch versions now have an option for treating local-scale dust storm effects, rather than just the global-scale dust storms in the original Mars-GRAM. (3) The Zurek wave perturbation model has been added, to simulate the effects of tidal perturbations, in addition to the random (mountain wave) perturbation model of the original Mars-GRAM. A minor modification has also been made which allows heights to go "below" local terrain height and return "realistic" pressure, density and temperature, not the surface values, as returned by the original Mars-GRAM. This feature will allow simulations of Mars rover paths which might go into local "valley" areas which lie below the average height of the present, rather coarse-resolution, terrain height data used by Mars-GRAM. Sample input and output of both the interactive and batch versions of Mars-GRAM are presented.

## **APPENDIX C**

### **MARS-GRAM RELEASE #2 TECHNICAL REPORT**

This Appendix contains the technical portions of the Release #2 Report for Mars-GRAM (version 3.1), "The Mars Global Reference Atmospheric Model (Mars-GRAM) Release #2", Bonnie F. James (Grant Monitor) and C. G. Justus, March 1, 1993, prepared under Georgia Tech grant NAG8-877 for NASA Marshall Space Flight Center. Appendix material (giving outdated information on program input, output, and running characteristics) has been deleted.

## INTRODUCTION

The Mars Global Reference Atmospheric Model (Mars-GRAM; Justus and Chimonas, 1988; Justus, 1990, 1991), includes simulation capabilities for mean values of density, temperature, pressure and wind components. Density perturbations, simulated by a mountain-wave simulation model are also included, for simulation of density perturbation profiles along specified trajectories through the atmosphere of Mars.

Up to a height of 75 km, Mars-GRAM is based upon parameterizations of height, latitudinal, longitudinal and seasonal variations of temperature, determined from a survey of published measurements from the Mariner and Viking programs ( a complete set of references is provided by Justus and Chimonas, 1989). Pressure and density are inferred in Mars-GRAM from the temperature by making use of the hydrostatic and perfect gas law relationships. Above about 120 km, Mars-GRAM uses the thermospheric model of Stewart (1987). A hydrostatic interpolation routine is used to insure a smooth transition from the lower portion of the model to the Stewart thermosphere model.

Mars-GRAM includes parameterizations to simulate the effects of seasonal variation, diurnal variation, dust storm effects, effects due to the orbital position of Mars, effects of the large seasonal variation in surface atmospheric pressure because of differential condensation/sublimation of the CO<sub>2</sub> atmosphere in the polar caps, and effects of Martian atmospheric mountain wave perturbations on the magnitude of the expected density perturbations. The thermospheric model includes a parameterization for the effects of solar activity, measured by the 10.7 cm solar radio flux. Winds are computed by the thermal wind approximation, with the inclusion of the effects of molecular viscosity, which, because of the low atmospheric densities, can be very important at high altitudes. The mountain wave perturbation model also includes a damping approximation due to the effects of molecular viscosity.

During much of 1990 and early 1991, the Mars Atmosphere Knowledge Requirements Working Group (Bourke, 1991) met by video-conference, with the objectives of

- Understanding the sensitivity and consequences of various levels of uncertainties in the Martian atmosphere
- Understanding the realistic limits on modeling the Mars atmosphere, both deterministically and statistically
- Recommending a set of atmospheric information requirements to be satisfied by the robotic portion of the Mars Exploration Program

Specific recommendations were made by the working group for improvements and additions to the Mars-GRAM program:

- (1) The addition of a capability to treat local-scale dust storms. The current Mars-GRAM treats all storms as growing and decaying with time, but with a size of full global dimensions.
- (2) The addition of the Zurek wave model (Pitts et al., 1988) to represent the large-scale temperature and density perturbations caused by atmospheric tides. The current Mars-GRAM perturbations are rather small-scale, gravity-wave-like variations.

- (3) A modular version of Mars-GRAM, specifically designed for use as a subroutine in a calling program, such as a trajectory guidance and control analysis program. This version would allow easy application of user-defined perturbation models, such as sine-wave perturbations or hyperbolic tangent or step-like perturbations.

The purpose of this report is to describe the Mars-GRAM modifications recently made to satisfy these recommendations.

## **ADDITIONS TO MARS-GRAM**

### **The Zurek Wave Perturbation Model**

Parameters necessary to evaluate wave-structure perturbations in temperature are provided by Zurek's tables on pages 11-12 of Pitts et al. (1988). The Zurek wave model was designed to allow estimation of temperature perturbations which would be produced by atmospheric tides (expected to be an important process in the Martian atmosphere). In order to compute wave-structure perturbations in density from the original temperature perturbation estimates of Zurek, a simple model is assumed, based on approximate hydrostatic equilibrium for these large-scale perturbations. The perfect gas law,  $p = \rho RT$ , requires that perturbations in pressure, density and temperature be related (to first order) by

$$p'/\langle p \rangle = \rho'/\langle \rho \rangle + T'/\langle T \rangle \quad , \quad (1)$$

where the angle brackets denote average values. The perturbation version of the hydrostatic equations,  $\partial p'/\partial z = -\rho'g$ , requires that

$$\partial(p'/\langle p \rangle)/\partial z = -(\rho'/\langle \rho \rangle - p'/\langle p \rangle) (g/RT) = -(T'/\langle T \rangle) (g/RT) \quad . \quad (2)$$

If one assumes a simple cosine function for the vertical variation of  $T'/\langle T \rangle$ , i.e.,

$$T'/\langle T \rangle = A \cos(kz) \quad , \quad (3)$$

then equations (1) and (2) require that

$$\rho'/\langle \rho \rangle = A [\sin(kz) / (kH) - \cos(kz)] \quad , \quad (4)$$

where  $H$  is the scale height ( $RT/g$ ). The temperature perturbation data provided in Zurek's table provide information to determine the values of  $k$  and the wave amplitude  $A$  for both clear-sky and dust-storm cases. If it is assumed that  $kH \equiv 1$ , then the density perturbation may be evaluated from this  $k$  value, with the approximation form of equation (4), namely

$$\rho'/\langle\rho\rangle \cong A [\sin(kz) - \cos(kz)] \quad (5)$$

Figure 1 shows a sample evaluation of the Zurek density wave perturbation model at the location and time of the Viking 1 lander entry (7/20/76 12:30 GMT, at Mars latitude 22°N, longitude 48°W). Since the random (mountain-wave) perturbations no longer constitute the only perturbations in Mars-GRAM, their minimum acceptable perturbation magnitudes have been decreased somewhat. A sample of the random density perturbations at the Viking 1 lander location and time is shown in Figure 2. The total density perturbations, found by adding the wave-component and random-component perturbations from Figures 1 and 2, are consistent with the density perturbations observed by the Viking 1 and 2 landers (shown as figures in the Pitts et al. 1988 report), which have peak values of 10-20%.

Figure 3 shows the density wave perturbation values from the Zurek model, evaluated on a height-latitude cross section, through the Viking 1 longitude (48°N) at the time of the lander entry. Peak contour values in Figure 3 are +14% and -14% (not labeled because of the small area within these contours).

### **Local-Scale Dust Storm Simulations**

At run time, the Mars-GRAM user selects the time of start (within seasonal bounds) for a dust storm (if any) to be simulated. A time profile of build-up and decay for the dust storm intensity (up to a selectable maximum value) is part of the program. The new additions also allow selection of a location (latitude and longitude) at which the dust storm is to start and a maximum radius (up to 10,000 km) that the dust storm is allowed to grow. These parameters of dust-storm location and maximum radius ( $r_{\max}$ ) are used to compute a size factor which multiplies the intensity of the dust storm effects. The size factor, as a function of position and height, is given by

$$\text{size factor} = 0.25 [1 + \cos(90^\circ r/r_d)][1 + \cos(90^\circ z/z_d)] , \quad (6)$$

where  $r$  is the local radius from the dust storm center location,  $r_d$  is the temporally varying dust-storm radius (up to a maximum of  $r_{\max}$ ),  $z$  is the local height and  $z_d$  is the height of the dust storm.  $z_d$  also grows temporally up to a maximum value of 60 km or  $r_d/3$  (whichever is smaller).

The dust storm radius  $r_d$  and height  $z_d$  are values for 1/2 the full effect. Thus the size factor given by equation (6) is 1 when  $r/r_d = 0$  and  $z/z_d = 0$ ; it is 1/2 when  $r/r_d = 1$  and  $z/z_d = 1$ ; and it is 0 when  $r/r_d = 2$  or  $z/z_d = 2$ . As illustrated by Figure 4 the function  $0.5[1 + \cos(x)]$  used in equation (6) is very similar to the Gaussian distribution function  $\exp(-x^2/\pi)$  frequently used as a size factor function in diffusion models.

Figure 5 illustrates the effects of a local dust storm on the mean density simulated along a hypothetical trajectory, starting at latitude 0°N, longitude 0°W at 40 km altitude, and moving at constant height and latitude along longitude from 0 to 100°W, with a local dust storm centered at latitude 0°N, longitude 50°W, with radius = 1000 km. The values plotted in Figure 5 are the differences between mean density with dust storm perturbation and that with no dust storm effects.

Deviations in mean density of 25% or more are seen near the center position of the local storm, with 0 deviations seen at distances from the storm center of more than twice the storm radius.

### **The Mars-GRAM Batch Version**

A new batch version of Mars-GRAM has been developed, which uses NAMELIST input, and is completely modular, so that the main driver program can easily be replaced by any calling program, such as a trajectory simulation program. As with the interactive version, fixed values of trajectory displacements in height, latitude, longitude and time may be read in as input, or position along an arbitrary trajectory may be read in from an input file. In the batch version of Mars-GRAM, values of the trajectory displacement values can easily be changed with time by simple modifications to the short driver program, or from within the trajectory program which replaces the Mars-GRAM batch version driver program.

## **ADDITIONS TO MARS-GRAM**

The wave perturbations are modeled in a new subroutine WAVEPERT and associated functions AMPRINT and PHASINT to interpolate wave amplitudes and phases. The Zurek wave model parameters are input to the program via a new BLOCK DATA routine. The local dust storm modifications are incorporated into the previous subroutine DUSTFACT.

Other program modifications are that:

- (1) A minor modification has also been made which allows heights to go "below" local terrain height and return "realistic" pressure, density and temperature, not the surface values, as returned by the original Mars-GRAM. This feature will allow simulations of Mars rover paths which might go into local "valley" areas which lie below the average height of the present, rather coarse-resolution, terrain height data used by Mars-GRAM.
- (2) For simulations which are to follow the Mars-GRAM terrain heights exactly, an input height below -5 km will specify this option.
- (3) For 1-D plots versus either of the height variables (height above reference ellipsoid or above local terrain), the plotable output files have the height variable in the second (y) position (ordinate). This simplifies input to plot routines which do not allow run-time selection of which input variable is the abscissa and which is the ordinate.

## **DIGITAL TERRAIN DATA**

A new set of digital terrain height data for Mars, produced by the U.S. Geological Survey, has been received on large format magnetic tape. The feasibility of extracting a more detailed set of terrain heights from this set, for improvement over those currently used by Mars-GRAM, has been examined. Some potential problems with this are that the data on DEC VAX format tapes (we have no easy access to a DEC VAX with 9-track tape drives), and the data on the tapes are in "pixel" form



for ease in producing images, not necessarily for extracting tabular data at an array (e.g.,  $1^\circ \times 1^\circ$ ) of fixed locations.

This digital terrain model data base is now available on CD-ROM (Batson, 1992), and has been ordered in this format. However, the data were not received in time to process during this contract period.

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Batson, R. M., et al. (1992). CD-ROM Publication of the Mars Digital Cartographic Data Base, NTIS HC/MF A25.

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Justus, C. G. and G. Chimonas (1989). The Mars Global Reference Atmospheric Model (Mars-GRAM). NASA MSFC Technical Report, ORIG 7-20-89, REV1 10-8-89.

Pitts, D. E., J. E. Tillman, J. Pollack and R. Zurek (1988). Model Profiles of the Mars Atmosphere for the Mars Rover and Sample Return Mission, draft technical report, March 11.

Stewart, A. I. F. (1987). Revised Time Dependent Model of the Martian Atmosphere for use in Orbit Lifetime and Sustenance Studies. Final Report JPL PO# NQ-802429, March 26.

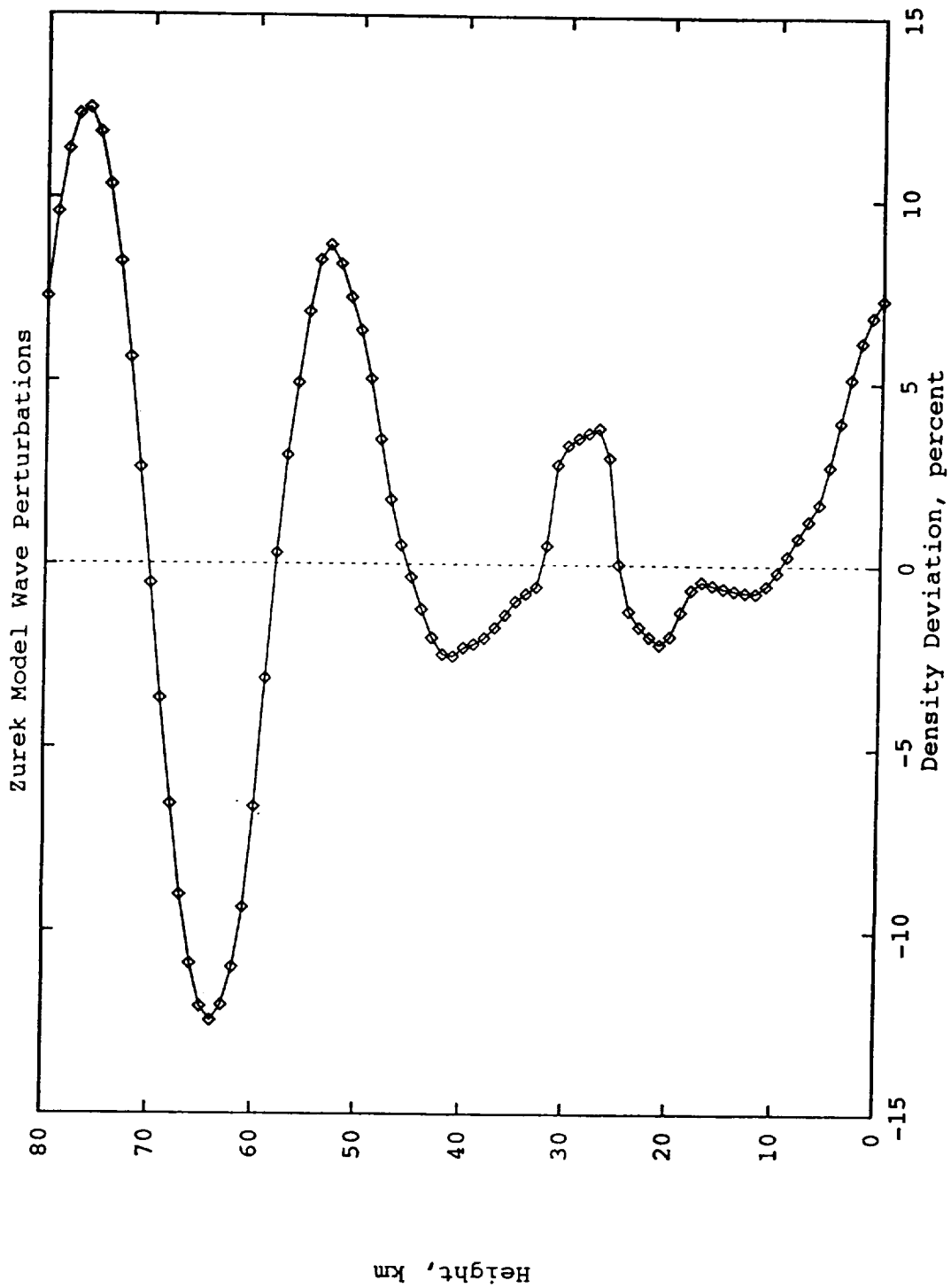


Figure 1 - Sample evaluation of the Zurek density wave perturbation model (based on temperature perturbation parameters in Pitts et al., 1988). Location and time corresponds to that of the Viking 1 Lander entry (22°N 48°W, 12:30 GMT on 7/20/76).

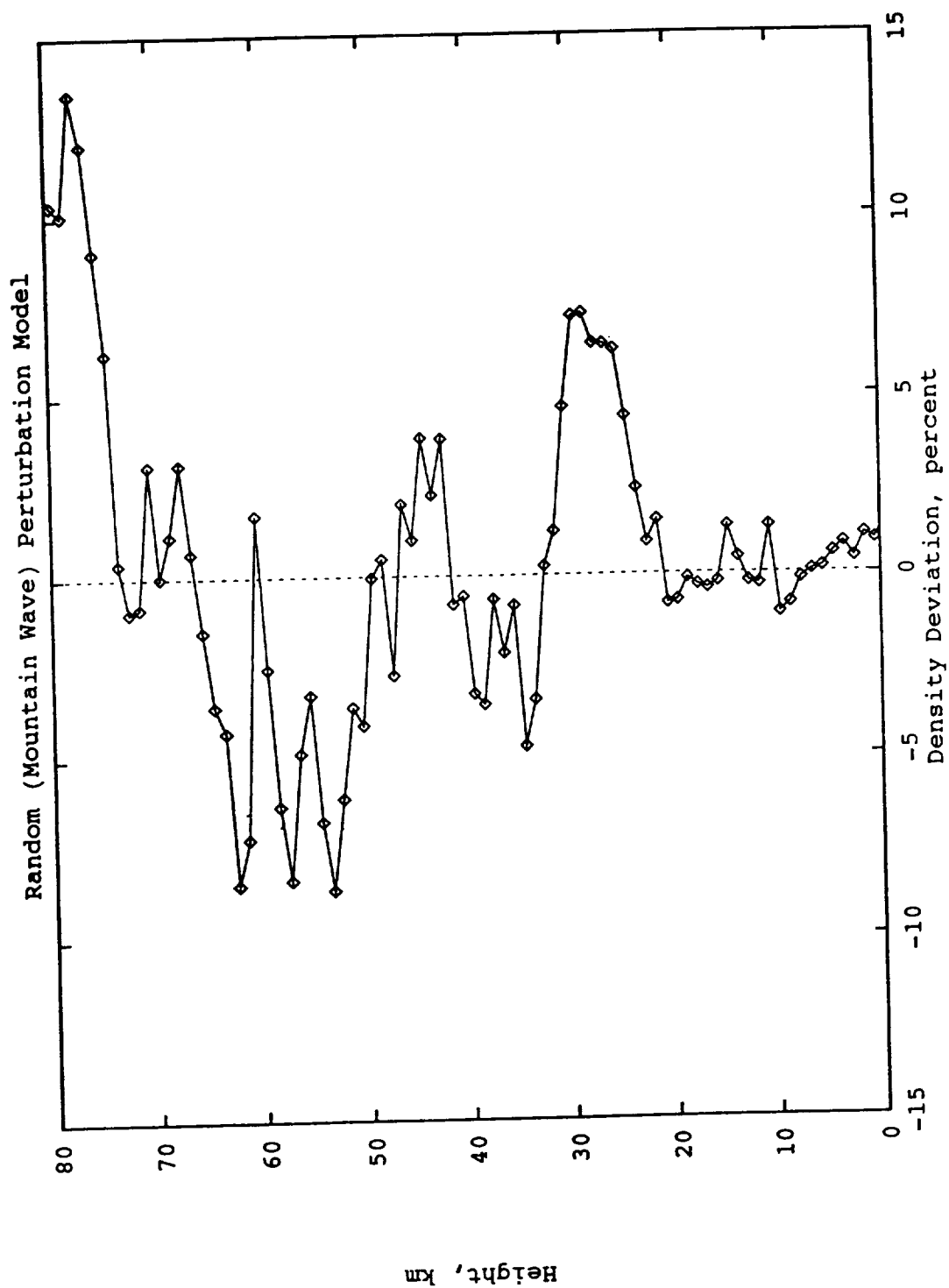


Figure 2 - Random (mountain-wave) perturbations in density, evaluated for the same location and time as in Figure 1.

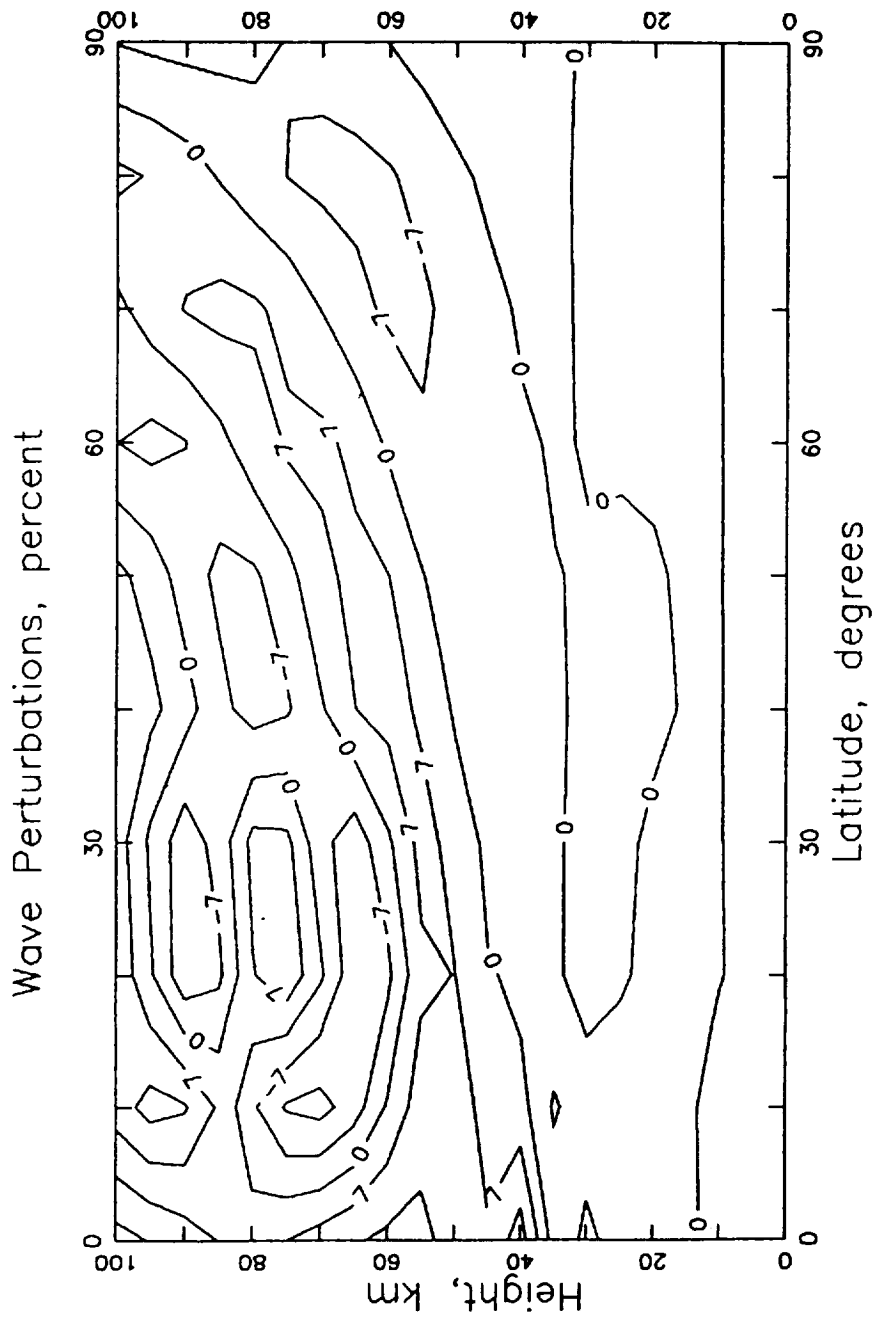


Figure 3 - Zurek density wave perturbations evaluated along a height-latitude cross section through the longitude 48°W at the time of the Viking 1 Lander entry.

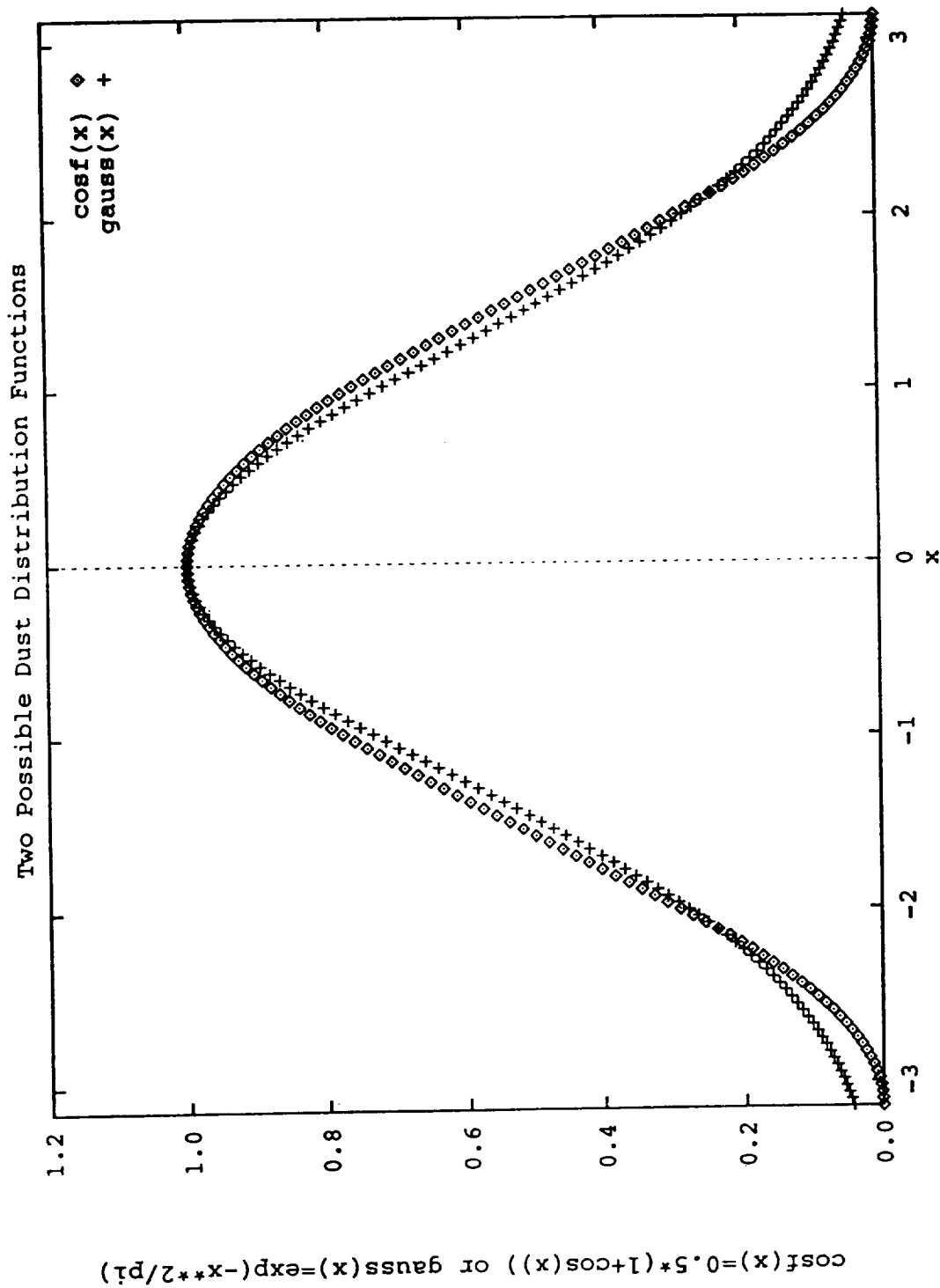


Figure 4 - Comparison of two possible spatial distribution model functions for local-scale dust storms.  $\text{cosf}(x) = 0.5[1 + \cos(x)]$ , for  $-\pi \leq x \leq \pi$ , with  $x$  in radians, and  $\text{gauss}(x) = \exp(-x^2/\pi)$ . The functions are normalized to 1 at  $x=0$ , with the area under  $\text{cosf}(x)$  from  $-\pi \leq x \leq \pi$  the same as the area under  $\text{gauss}(x)$  from  $-\infty \leq x \leq +\infty$ .

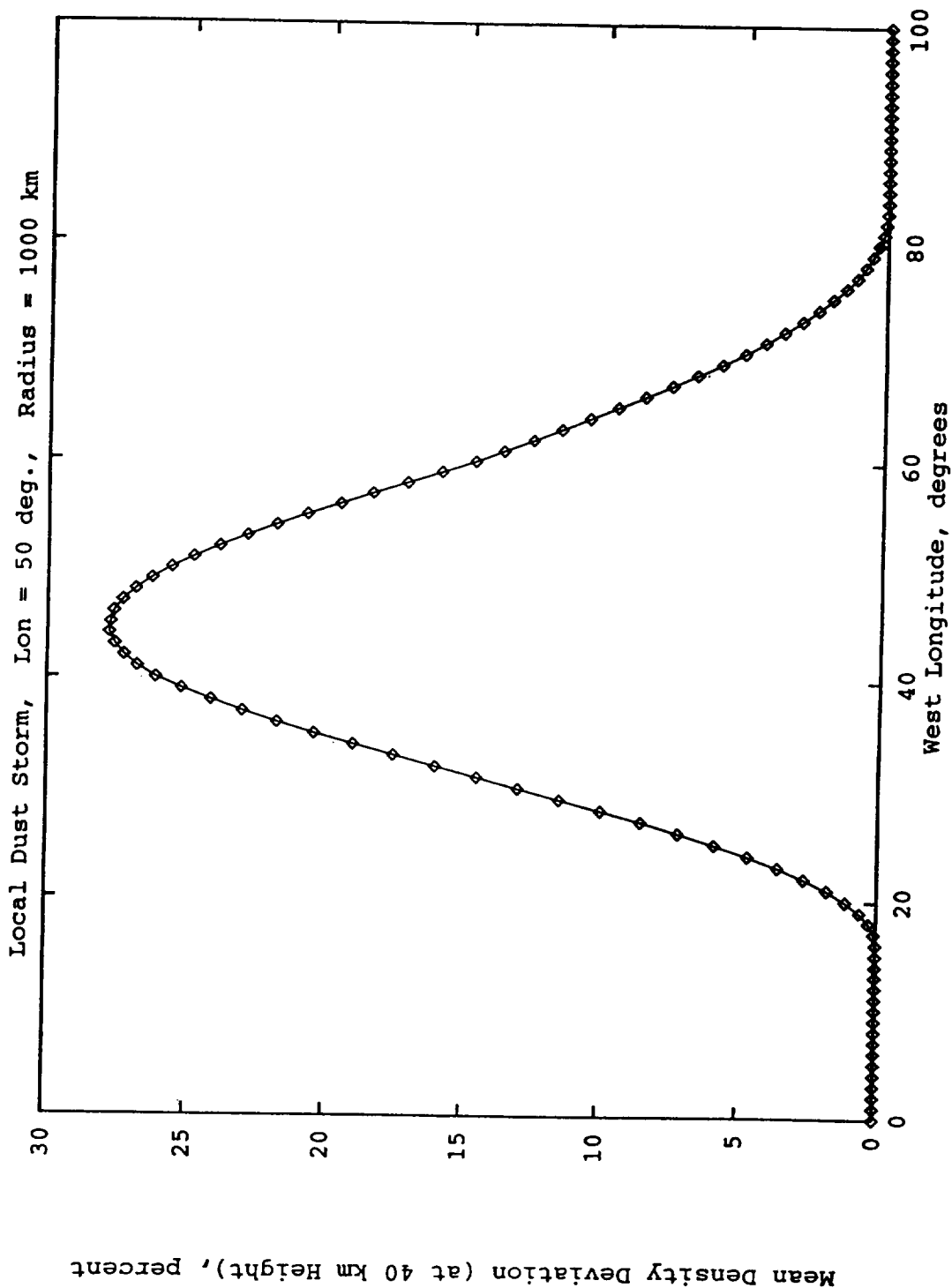



Figure 5 - The effect on mean atmospheric density due to a local dust storm of radius 1000 km, centered at 0°N, 50°W. Density was evaluated along a trajectory at a constant height of 40 km from 0°N, 0°W to 0°N, 100°W. Mean density deviations are in percent, relative to density in the non-dust storm case.

## APPROVAL

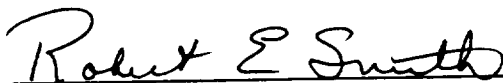
### MARS GLOBAL REFERENCE ATMOSPHERIC MODEL (MARS-GRAM 3.34): PROGRAMMER'S GUIDE

C. G. Justus, Bonnie F. James and Dale L. Johnson

The Information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classifications Officer. This report, in its entirety, has been determined to be unclassified.



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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, Va 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave Blank)		2. REPORT DATE May 1996		3. REPORT TYPE AND DATES COVERED Technical Memorandum
4. TITLE AND SUBTITLE  Mars Global Reference Atmospheric Model (Mars-GRAM 3.34): Programmer's Guide			5. FUNDING NUMBERS	
6. AUTHOR(S)  C.G. Justus*, B.F. James and D.L. Johnson				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812			8. PERFORMING ORGANIZATION REPORT NUMBERS	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  National Aeronautics and Space Administration Washington, DC 20546-0001			10. SPONSORING/MONITORING AGENCY REPORT NUMBER  NASA TM-108509	
11. SUPPLEMENTARY NOTES Prepared by Electromagnetics and Aerospace Environments Branch, System Analysis and Integration Laboratory, Science and Engineering Directorate. *Computer Sciences Corporation, Huntsville, Alabama				
12a. DISTRIBUTION/AVAILABILITY STATEMENT  Unclassified - Unlimited			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  This is a programmer's guide for the Mars Global Reference Atmospheric Model (Mars-GRAM 3.34). Included are a brief history and review of the model since its origin in 1988 and a technical discussion of recent additions and modifications. Examples of how to run both the interactive and batch (subroutine) forms are presented. Instructions are provided on how to customize output of the model for various parameters of the Mars atmosphere. Detailed descriptions are given of the main driver programs, subroutines, and associated computational methods. Lists and descriptions include input, output, and local variables in the programs. These descriptions give a summary of program steps and "map" of calling relationships among the subroutines. Definitions are provided for the variables passed between subroutines through "common" lists. Explanations are provided for all diagnostic and progress messages generated during execution of the program. A brief outline of future plans for Mars-GRAM is also presented.				
14. SUBJECT TERMS Mars Global Reference Atmospheric Model, thermosphere, atmospheric temperature, pressure, wind components, atmospheric models			15. NUMBER OF PAGES 189	
			16. PRICE CODE NTIS	
17. SECURITY CLASSIFICATION  Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT  Unlimited	



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